CITY OF SPOKANE

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January 26, 2022

Cooper Garbe
Department of Ecology
Air Quality Program
P.O. Box 47600
Olympia, WA 98504-7600

RE: City of Spokane Comments on Informal Draft of Chapter 173-446 WAC

Dear Mr Garbe:

The City of Spokane (the "City") offers the following comments during the informal comment period on the draft Chapter 173-446 WAC – Climate Commitment Act Program Rule (the "Proposed Rule") as it applies to the City's municipal Waste to Energy Facility (the "WTEF"). The Proposed Rule would implement the cap-and-invest program under the Washington Climate Commitment Act, which was adopted in 2021.

The overarching purpose of the Climate Commitment Act is to mitigate the negative impacts of greenhouse gases on the environment and human health, and especially those impacts that have disproportionately burdened vulnerable communities. The City's comments reflect our concern that the Proposed Rule, as written, actively works against the stated goals of the Climate Commitment Act when applied to the City's WTEF. The City respectfully requests that the Department of Ecology ("Ecology") revise the Proposed Rule to:

- acknowledge the environmental, greenhouse gas emission reduction, and environmental justice benefits associated with waste-to-energy operations;

- provide equal or similar treatment of all municipal solid waste management facilities (i.e., waste-to-energy operations treated similarly to landfills);

- factor an appropriate and accurate accounting of avoided emissions associated with waste-to-energy operations when determining the Proposed Rule's applicability to those facilities to prevent the unintended/unwanted consequence of actual increases of greenhouse gases when life cycle emissions are accounted; and

- provide credits that account for lifecycle emission reductions at waste-to-energy operations, allowing for a true evaluation of solid waste management greenhouse gas emissions.

The City appreciates the opportunity to offer Ecology comments on the Proposed Rule. Below we provide additional detail and context for our comments.

I. Introduction

The City operates the only municipal WTEF in Washington State.[1] The WTEF is an integral part of the Spokane County Solid Waste Management Plan. The WTEF can process up to 800 tons of municipal solid waste a day. The disposal process burns the solid waste at 2,500 degrees and reduces the solid waste 90 percent by volume and 70 percent by weight. The resulting ash is biologically inactive and is sent to a landfill in Klickitat County for disposal and for resource recovery and/or re-use.

The primary purpose of the WTEF is to manage municipal solid waste for the Spokane Region. Combustion of solid waste provides the dual benefit of effectively managing solid waste and avoids decades of landfill methane emissions. The WTEF represents critical infrastructure for the City and protects the region's sole source aquifer. The State of Washington recognized that construction of the WTEF avoided the water quality risks presented by a landfill, and therefore, was deemed the best waste disposal option for the region. Washington provided an initial $60 million investment in the construction of the WTEF via an Ecology grant pursuant to State Referendum 39. In addition to protecting the City's sole source aquifer, the WTEF captures the energy associated with combustion of waste materials to generate electricity that is sold to the regional electric utility, thereby displacing virgin fossil fuel sources of energy.[2]

The Proposed Rule will result in millions of dollars of added costs to the citizens of Spokane as well as lost revenues to the City. The costs and lost revenues will be a direct result of the Proposed Rule's disparate treatment of landfills as compared to waste-to-energy facilities. Under the Proposed Rule, a landfill can avoid becoming subject to the Rule by capturing 75% of the methane gas generated and operating a program to produce renewable natural gas or electricity from the captured gas. By comparison, waste-to-energy facilities generate no methane and more efficiently convert all of the energy content in solid waste to power and yet do not have a similar compliance pathway under the Proposed Rule.

The bottom line: the Proposed Rule will force the City to make an untenable choice of increasing the cost of waste disposal at the WTEF to comply with the Proposed Rule, or closing the WTEF and opting for alternative waste disposal in landfills hundreds of miles away.

Closure of the WTEF will result in waste disposal in landfills far from their point of origin. Similarly, an increase in the costs of waste disposal at the WTEF will result in entities evaluating whether to deliver waste materials to the WTEF or to ship those waste materials to landfills that bear a disproportionately lower cost of compliance under the Proposed Rule. As such, the Proposed Rule manifestly contradicts the

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[1] RCW 70A.205.010 assigns primary responsibility for solid waste handling (collection and disposal) to local governments. RCW 70A.205.040 requires a coordinated comprehensive solid waste management plan (SWMP) which address final disposal of solid waste. In Spokane County, final disposition is by combustion at the City's Waste to Energy Facility.

[2] A recent WUTC decision established that the City WTEF's primary purpose was managing solid waste and it's generation of electricity was an ancillary function; as such, the WTEF is not 'baseload electric generation' under Chapter 80.80 RCW. *See In the Matter of the Petition of City of Spokane*, Declaratory Order, Docket UE-210247 (July 23, 2021 W.U.T.C.).

Legislature's intent in enacting the Climate Commitment Act. Shipping waste hundreds of miles from where it is generated, only to dispose of it in a manner that increases greenhouse gas emissions, is exactly the type of action the Climate Commitment Act sought to avoid. Closure of the WTEF in exchange for sending solid waste to remote landfills would cause negative impacts to overburdened, vulnerable communities; emissions leakage; and increased lifecycle emissions. This result is not what the Legislature intended in passing legislation aimed at addressing those very issues.

The City requests that Ecology consider the following impacts of the Proposed Rule. First, the City's analysis of the costs associated with the Proposed Rule suggest that it would impose over $2 million per year in additional costs on the WTEF, which could force the City to close the WTEF. Second, the Proposed Rule does not provide equal or similar treatment of municipal solid waste management facilities, despite the fact that municipal waste management is an essential function of all local government. Third, the Proposed Rule does not provide for appropriate or accurate accounting of avoided emissions associated with waste-to-energy facilities, resulting in an inaccurate estimate of the actual emission impacts of these facilities. Finally, the Proposed Rule does not provide offsets or credits that account for lifecycle emission reductions at waste-to-energy operations.

II. Comments on the Proposed Rule

a. Impacts of the Proposed Rule on WTEF

i. *Closure of the City's WTEF*

The Proposed Rule will impose costs on the Spokane WTEF that could force its closure. While the precise cost of implementing the Proposed Rule is uncertain, the City's best estimate projects the anticipated additional costs to conservatively be between $2 million and $2.5 million per year. The City assumes, at minimum, a carbon price of $25/metric ton (though some carbon-pricing models indicate prices could be much higher).[3] The City also understands that prices will escalate over time. Based on a review of the City's past five years of greenhouse gas reporting, and without a revision to the Proposed Rule allowing for offsets or credits that account for lifecycle emission reductions at the WTEF, the likely carbon price would render the WTEF financially unviable. One alternative presented would be to invest in and install carbon capture technology.[4] While this technology is still in its infancy, and therefore budgetary estimates

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[3] This estimate is derived, in part, by reference to a similar carbon price imposed in California at a rate of $28.26/metric ton. Additionally, a report from McKinsey and Company on carbon price forecasting lists $40/metric ton recommend by economists. *See* McKinsey & Company, The state of internal carbon pricing (Feb. 10, 2021), https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/the-state-of-internal-carbon-pricing. The pricing estimate adopted by the City is therefore a conservative estimate.

[4] The federal program authorizing the geological sequestration of carbon dioxide, as regulated through the Underground Injection Control program of the Safe Drinking Water Act, is not likely a viable solution for the City because of the location and critical importance of the sole source aquifer.

are difficult to project, the City estimates adopting carbon capture technology would require approximately $70 million in capital investments plus unknown operation and maintenance costs.

In either scenario, the City would be required to pass on the increased costs to the citizens of Spokane or shut down the WTEF and search for a financially viable replacement for the City's current solid waste disposal facility. Given the magnitude of the costs involved, the City is both unable and unwilling to recoup those expenses from its citizens. Therefore, the closure of the Spokane WTEF is a likely outcome. As a result, the City would need to ship its municipal solid waste to landfills that offer an economically competitive service. The City is extremely concerned about this outcome because it will result in the loss of approximately 50 jobs, elimination of 19 megawatt-hours (MWh) from the local electrical grid, the loss of approximately $5.2 million in public works contracts and $8.1 million in personal service contracts annually, the loss of approximately $74.9 million in total economic output from the WTEF, and the outsourcing of Spokane County's municipal solid waste to other counties in Washington State or the surrounding region.

ii. ***Elimination of the Benefits of the WTEF Following Closure Frustrates the Intent of the Climate Commitment Act***

If the WTEF is forced to close due to the increased costs of compliance associated with the Proposed Rule, the intent of the Climate Commitment Act would be frustrated. The Climate Commitment Act seeks to reduce greenhouse gas emissions and protect vulnerable communities from the effect of emissions. Closure of the WTEF would result in a significant net increase in the amount of greenhouse gas emissions produced by the municipal waste generated in the Spokane area because the waste would be sent to a landfill where it will generate methane.

Furthermore, no new landfills may be created in the Spokane region because to do so would threaten the sole source aquifer located directly below the region. As such, closure of the WTEF would necessarily entail shipping municipal waste by rail or truck to distant locations for landfilling. This outsourcing of waste will generate additional emissions related to transportation, and it would also increase the environmental justice burden on potentially vulnerable communities located near landfills that continue to accept municipal waste. The benefits of the WTEF—in the form of avoided emissions, recovery and recycling of metals, and ancillary generation of electricity—would also be lost if the Proposed Rule is finalized as written.

These results run directly contrary to the stated intent of the Climate Commitment Act. Accordingly, Ecology should revise the Proposed Rule to acknowledge and meaningfully account for the myriad of benefits associated with waste-to-energy operations. Below we describe in detail the benefits of the WTEF.

1. Reduction in Methane Emissions

Compared to landfill gas-to-energy operations, waste-to-energy operations have fewer lifecycle inventory emissions. The difference is because of the quantity of methane emitted by landfills.[5] Because methane has a global warming potential of 25 times that of CO_2, the CO_2e emissions from landfill gas-to-energy operations may be larger than those of waste-to-energy operations. A recent paper found that the CO_2e emissions from landfills were significantly higher than the emissions from other alternatives because of the relatively high methane emissions. As a result, landfill gas-to-energy operations have greater greenhouse gas emissions impacts than waste-to-energy operations.[6] The Proposed Rule fails to account for this relative reduction in CO_2e when waste-to-energy operations are used to handle municipal solid waste rather than landfills.

Furthermore, the EPA has studied municipal solid waste disposal to compare lifecycle emissions from either burning or burying solid waste and concluded that waste-to-energy operations produce fewer emissions than landfills.[7] In the relevant study, the EPA evaluated the total life cycle inventory of emissions from landfill gas-to-energy operations as the summation of emissions resulting from: (1) the site preparation, operation, and post closure operation of a landfill, (2) the decay of the waste under anaerobic conditions, (3) the equipment utilized during landfill operations and landfill gas management operations, (4) the production of diesel required to operate the vehicles at the site, and (5) the treatment of leachate. The total life cycle emissions of a waste-to-energy operation was quantified as the summation of: (1) the combustion of waste, i.e., the stack gas (accounting for air pollution controls), (2) the production and use of limestone in the air pollution control technologies (i.e., scrubbers), and (3) the disposal of ash in a landfill.

EPA's analysis shows that the greenhouse gas emissions for a waste-to-energy operation range from 0.4 to 1.5 MTCO2e/MWh; by comparison, the most optimistic landfill gas-to-energy scenario results in 2.3 MTCO2e/MWh, yet could be has high as 5.5 MTCO2e/MWh. Additional modeling by the EPA similarly shows that waste-to-energy operations actually reduce the amount of greenhouse gases in the atmosphere compared to landfilling.[8]

The former branch chief of the EPA's Office of Solid Waste in Washington, D.C., William Brandes, has gone on the record supporting the use of waste-to-energy operations as a method of reducing the greenhouse gas emissions of landfills.[9] As Mr. Brandes notes in his commentary, methane is one of the most potent greenhouse gases and should be a top priority in the world's fight against climate change. Landfills are a

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[5] *See* P. Ozge Kaplan et al., *Is it Better to Burn*, 43 Environ. Sci. Tech. 973, 1711 (2009).

[6] *Id.* at 1714.

[7] *See* Marco J. Castaldi, Ph.D., *Scientific Truth About Wates to Energy* at 12 (2020), https://static.spokanecity.org/documents/solidwaste/wastetoenergy/wte-report-2021.pdf.

[8] *See* EPA, *Air Emissions from MSW Combustion Facilities*, https://archive.epa.gov/epawaste/nonhaz/municipal/web/html/airem.html.

[9] William Brandes, A solution to Man-made Methane (unpublished submission to The Wall Street Journal).

key source of methane emissions and solid waste generation is a huge and growing global issue. For example, the U.S. alone produces almost 300 million tons of a garbage annually. While efforts have been made to reduce waste and recycle, these efforts are simply not keeping pace with the volume of waste generated and recycling rates have remained flat since 2010.

Waste-to-energy operations offer a prime opportunity to reduce methane generation created by the landfilling of increasingly large volumes of solid waste. Waste-to-energy's capacity for reducing methane emissions from solid waste is especially relevant today, as the United States has signed on to the Global Methane Pledge.[10] The United States has agreed to take action to reduce global methane emissions at least 30 percent from 2020 levels by 2030. Waste-to-energy operations offer a viable means to help achieve these methane reduction goals.

2. *Recovery of Ferrous and Non-ferrous metals*

Waste-to-energy operations also allow for the recovery of ferrous and nonferrous metals, which avoids the additional energy consumption that would be required if the same metals were produced from virgin ores. Waste-to-energy operations in the United States currently recover nearly 700,000 tons of ferrous metal for recycling annually, which avoids CO_2 emissions and saves energy consumption.[11] The WTEF recovers over 9,000 tons of ferrous metals from solid waste annually.[12] Notably, the landfill which currently accepts the WTEF's ash has been *mining* the ash disposed over the years to recover additional metals now that the technology and markets exist to support those efforts.

Universities and companies, such as Columbia University,[13] Rutgers,[14] and Lixivia,[15] are working on ash utilization projects that would enhance metal recovery beyond current capabilities. Beyond recovery of ferrous and nonferrous metals, several projects are researching the mining of precious metals and elements from ash, thereby reducing the environmental impacts of mining for precious metals as well.[16]

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[10] *See* Global Methane Pledge, About, https://www.globalmethanepledge.org/#about.

[11] Marco J. Castaldi, Ph.D., *Scientific Truth About Waste-to-Energy* at 13.

[12] This is the amount recovered post combustion, even after a robust recycling program. As a comparison, pre-combustion ferrous metals recycled are about 1,700 tons annually. In essence, using the WTE technology allows for recovery of over 5 times more ferrous metal.

[13] ARPA-E, *Columbia University, Integrated CO2-facilitated Hydrometallurgical and Electrochemical Technology for Sustainable Mining and Recovery of Critical Elements from Wastes and Ashes*, https://arpa-e.energy.gov/technologies/projects/integrated-co2-facilitated-hydrometallurgical-and-electrochemical-technology.

[14] ARPA-E, *Rutgers University, Waste-to-Energy (WTE)-Derived Low-Carbon-Footprint Concrete (LCFC)*, https://arpa-e.energy.gov/technologies/projects/waste-energy-wte-derived-low-carbon-footprint-concrete-lcfc.

[15] ARPA-E, *Lixivia, Using Bio-inspired Lixiviants to Selectively Extract Valuable Metals from Municipal Solid Waste Incinerator Ash*, https://arpa-e.energy.gov/technologies/projects/using-bio-inspired-lixiviants-selectively-extract-valuable-metals-municipal.

[16] *See* ARPA-E, *Mining Incinerated Disposal Ash Streams*, https://arpa-e.energy.gov/technologies/exploratory-topics/metal-recovery.

The City is participating with some of these researchers by providing ash samples when requested, and the City looks forward to participating in new initiatives whenever possible.

3. *Minimizing Leakage*

If the WTEF were shut down, all regional municipal solid waste that is not recycled would likely be sent to a landfill that is located approximately 200 miles away in Klickitat County.

This outsourcing of solid waste would have the same effect as emissions leakage because emissions from landfilling the redirected waste would be considerably higher than those produced by the WTEF. The overall result is a negative impact to the environment.

Moreover, because the City is required to competitively bid for waste disposal services, the future economics of solid waste disposal could favor landfills located outside the City or even Washington State. The result is that Washington-generated waste could be transported and disposed in other landfills in the state that do not have the same requirements as the WTEF under the Proposed Rule, or be disposed of in out-of-state landfills where state laws do not have similar rules or incentives around reducing greenhouse gas emissions. For instance, both Idaho and Montana do not have similar regulatory requirements as Washington. In either scenario, where solid waste is shipped from Spokane to a landfill, the trucking of solid waste will also generate emissions due to the combustion of fuel used for transportation.

4. *Innovation to be Global Leaders in a Low Carbon Economy*

Waste-to-energy operations allow municipal solid waste management programs to innovate and provide considerable greenhouse gas emission reductions compared to landfills. For instance, coal fly ash and steel slag are critical to high performance construction materials, but both of these wastes are in decline. Waste-to-energy operations allow for recovery and production of these materials.[17] As mentioned previously, waste-to-energy operations are capable of recovering significant quantities of metals, which can then be reused and recycled. New technologies are also emerging that include the use of novel compounds which can produce useful industrial materials from incinerated waste while simultaneously scrubbing CO_2 from stack gases.[18] Waste-to-energy operations can more effectively harness the resource value from waste before disposing of the remaining residuals, all while reducing the amount of methane and other greenhouse gases produced compared to landfilling.

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[17] *See, e.g.*, Alicja Uliasz-Bocheńczyk & Eugeniusz Mokrzycki, *The potential of FBC fly ashes to reduce CO2 emissions*, Scientific Reports 10, 9469 (June 11, 2020), https://doi.org/10.1038/s41598-020-66297-y; Dominic Bui Viet et al., *The use of fly ashes from waste-to-energy processes as mineral CO2 sequesters and supplementary cementitious materials*, J. Hazardous Materials Vol. 398 (Nov. 5, 2020), https://doi.org/10.1016/j.jhazmat.2020.122906.

[18] *See, e.g.*, Le, D. H. et al., *Lanthanide metal–organic frameworks for the fixation of CO_2 under aqueous-rich and mixed-gas conditions*, Journal of Materials Chemistry A (2021), https://doi.org/10.1039/D1TA09463G; Yafei Guo et al., *CO2 capture and sorbent regeneration performances of some wood ash materials*, Applied Energy Vol. 137 at 26-36 (Jan. 1, 2015).

5. *Environmental Justice Consequences of Closing the Spokane WTEF*

The WTEF allows the City to locally manage the Spokane region's solid waste. The alternative would be to outsource the City's solid waste disposal and associated environmental risks to other communities that might already be vulnerable or disproportionately affected by environmental impacts. The City is as concerned with environmental justice as is the Legislature and does not want to be forced to shift the burden of solid waste disposal to other jurisdictions.

The City's WTEF is regulated by the Spokane Regional Clean Air Agency, Ecology, and the Spokane Regional Health District. The facility operates under environmental permits that require a variety of pollution control and monitoring devices. Other forms of solid waste management, such as landfilling, are not subject to such stringent controls. Closure of the WTEF would result in transport of solid waste for landfilling in jurisdictions and communities that may not require the environmental oversight in place at the Spokane WTEF, or may already be overburdened by waste outsourced by larger municipalities. Other forms of solid waste management, such as landfilling, do not require such strict emissions control, measurement, recordkeeping and reporting, and as a result there is high uncertainty in the composition and generation of greenhouse gases and hazardous air pollutants emitted by such landfills, which affect local communities.

Air pollutants generated by the regular transport of municipal waste can also be significant. For instance, studies indicate that if New York City—which transports solid waste out of state for disposal— were to adopt waste-to-energy technology, it could avoid approximately 16,000 kilograms (35,264 lbs) of truck particulate emissions per year.[19] The air pollution caused by the transport of waste is a further environmental justice burden to communities, in addition to the emissions created by landfilling.

Waste-to-energy operations provide additional environmental benefits. Perhaps most notably is that the combustion process destroys pathogens, pharmaceuticals, and toxic organics and eliminates leachate generation. At the time that the WTEF was built, almost every landfill in the county was contaminating groundwater and facing closure and environmental remediation issues. Even now, with modern lined landfills, many experts say it is not a matter of "if" but "when" liners fail or landfilled contaminants otherwise find pathways to threaten the environment and health of local communities.

One such area of particular concern is "forever chemicals" such as PFAS. While toxic organics like PFAS are broken down in the combustion process,[20] landfilling has been linked with widespread environmental contamination, and landfill leachate has been described as the "major pathway by which [PFAS] exit

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[19] EPA, Technical Brief, Per- and Polyfluoroalkyl Substances (PFAS): Incineration to Manage PFAS Waste Streams (Feb. 2020), https://www.epa.gov/sites/default/files/2019-09/documents/technical_brief_pfas_incineration_ioaa_approved_final_july_2019.pdf.

[20] Arie Kremen, PhD, *Leachate is the Driving Force for PFAS Sequestration in Landfills*, Waste Advantage (Nov. 2, 2020), https://wasteadvantagemag.com/leachate-is-the-driving-force-for-pfas-sequestration-in-landfills/#:~:text=Landfill%20leachate%20is%20the%20major,those%20found%20in%20sanitary%20wastewaters.

modern Subtitle D municipal solid waste landfills."[21] Closure of the WTEF would result in the elimination of these benefits and lead to an increased burden on environmental justice communities.

***6.** Trends in the Waste-to-Energy Industry*

In North America, there are 85 waste-to-energy facilities—77 are located in the United States and eight in Canada.[22] The industry, which began operation in the United States in 1975,[23] has been making continuous progress towards sustainability goals. Recent trends in the waste-to-energy industry include upgrading existing metal recovery systems with advanced ferrous and nonferrous metal recovery systems; advanced combustion controls that result in reduced combustion air, improved combustion and burnout of waste, and reduced emissions that require downstream treatments; advanced air pollution control systems; improved operation and maintenance techniques; and use of reclaimed water for cooling systems.[24]

Recognizing the benefits of waste-to-energy operations, some U.S. states have expressly included these operations as part of state renewable portfolio standards.[25] Looking overseas, many European countries utilize waste-to-energy operations to meet energy demands, including Scotland. The Scottish Environmental Protection Agency acknowledges that "[e]nergy from waste could ultimately contribute up to 31% of Scotland's renewable heat target and 4.3% of our renewable electricity target under the Climate Change (Scotland) Act."[26]

Of particular relevance here, King County—the most populous county in Washington state—is considering constructing a waste-to-energy facility to handle the increasing amount of solid waste generated in that jurisdiction.[27] King County's 2019 feasibility study comparing the environmental impacts of a waste-to-energy operation versus transport of solid waste by rail and landfill disposal found:

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[21] *See also* Lang J.R. et al., *National Estimate of Per- and Polyfluoroalkyl Substances (PFAS) Release to US Municipal Landfill Leachate*, Env't Sci. & Tech., Vol. 51(4) at 2197 (Jan. 20, 2019).

[22] *See* King County Solid Waste Division, *Waste-to-Energy (WTE) Options and Solid Waste Export Considerations* at 12 (Sept. 28, 2017).

[23] *See* King County Solid Waste Division, *WTE Existing Conditions Memorandum* at 2 (Aug. 18, 2017).

[24] King County Solid Waste Division, *Waste-to-Energy (WTE) Options and Solid Waste Export Considerations* at 15 (Sept. 28, 2017).

[25] *See e.g.*, Mass. Gen. Laws Ch. 25A, § 11f(b) ("[A] renewable energy generating source is one which generates electricity using any of the following: . . . (6) waste-to-energy which is a component of conventional municipal solid waste plant technology in commercial use").

[26] Scottish Environment Protection Agency, *Energy From Waste*, https://www.sepa.org.uk/regulations/waste/energy-from-waste/#:~:text=Contact%20us-,What%20is%20energy%20from%20waste%3F,Change%20(Scotland)%20Act%202009.

[27] *See* Metropolitan King County Council News, *Dunn pursues committee of experts to chart pathway for 'waste-to-energy' plant and close landfill* (July 7, 2021), https://kingcounty.gov/council/news/2021/July/7-7-RDunn-WTE-committee-

> [A] net difference of 0.17 MTCO2E/ton of GHGs can be avoided by [waste-to-energy] compared to waste disposal at an out of county landfill using [transport by rail]. If carbon sequestration emission credits are not applied to the landfill, then a net difference of 0.38 MTCO2E/ton of GHG can be avoided by [waste-to-energy] compared to [landfilling], assuming a carbon sequestration credit of 0.21 MTCO2E/ton.[28]

Recently, there has been an increase in number of waste-to-energy facility expansions and additions to existing waste-to-energy campuses. For example, the City of Tampa, Florida, retrofitted one waste-to-energy operation; Lee County, Florida, expanded three of its facilities; new facilities were built in Honolulu, Hawaii, and Palm Beach County, Florida; and one new facility was built in Ontario, Canada.[29] A recent senate bill in Florida would appropriate $100 million in recurring funds for waste-to-energy operations, as the state seeks to further incentivize municipalities to use waste-to-energy operations as a way to reduce solid waste delivered to landfills and create energy.[30] As the quantity of municipal waste generated continues to increase nationwide, more jurisdictions are likely to consider using waste-to-energy operations as an effective and sustainable means of waste management.

The Proposed Rule would have a chilling effect on waste-to-energy facility development in Washington State, in contrast to local and national trends that recognize the environmental and greenhouse gas emission reduction benefits provided by those facilities.

b. The Proposed Rule Should Provide Waste-To-Energy Operations with Equal or Similar Treatment as Landfills

The Proposed Rule should treat waste-to-energy operations in the same manner as landfills because they are solid waste disposal facilities, not energy generation facilities.

This classification was confirmed by the Washington Utilities and Transportation Commission ("UTC") on July 23, 2021.[31] The City petitioned for, and obtained, a declaratory order from the UTC confirming that the WTEF did not meet the statutory definition of a "baseload electric generation" facility because its

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release.aspx#:~:text=King%20County%20Councilmember%20Reagan%20Dunn,the%20existing%20Cedar%20Hills%20Landfill; *see also* King County, *Waste-to-Energy and Waste Export by Rail Feasibility Study* (Sept. 2019).

[28] King County, *Waste-to-Energy and Waste Export by Rail Feasibility Study* at viii (Sept. 2019).

[29] King County Solid Waste Division, *Waste-to-Energy (WTE) Options and Solid Waste Export Considerations* at 15 (Sept. 28, 2017).

[30] S.B. 1764, Fla. Legis. (2022), Municipal Solid Waste-to Energy Program, https://www.flsenate.gov/Session/Bill/2022/1764. *See also* Kelly Hayes, Florida Politics, *Senate bill seeking to boost funds for waste-to-energy facilities heads to second committee* (January 25, 2022), https://floridapolitics.com/archives/489788-senate-bill-seeking-to-boost-funds-for-waste-to-energy-facilities-heads-to-second-committee/.

[31] *See In the Matter of the Petition of City of Spokane*, Declaratory Order, Docket UE-210247 (July 23, 2021 W.U.T.C.).

intended purpose is management of municipal solid waste, not electricity generation.[32] As such, the WTEF is categorically a solid waste disposal facility on par with a landfill in terms of its essential function. The WTEF should be on equal footing as other solid waste disposal facilities with respect to the requirements of the Proposed Rule as well.

The Proposed Rule and the revised reporting regulations under WAC Chapter 173-441 create an inequitable and unsupported disparity between landfills and waste-to-energy operations. Specifically, as a waste-to-energy operation, the WTEF is required to report all biogenic CO_2 emissions.[33] However, landfills are required to report only biogenic CO_2 that is derived from methane generated in the landfill and then combusted for purposes other than flaring or destruction.[34] In other words:

- landfills are not required to report biogenic CO_2 generated during the decomposition process; and
- landfills are not required to report biogenic CO_2 generated from flaring landfill gas.

As a result, landfills do not report the total amount of biogenic CO_2 they emit. Rather, landfills report only a small fraction of their actual CO_2 emissions. In comparison, waste-to-energy operations are required to report all of their biogenic and nonbiogenic CO_2 emissions.

These discrepancies in reporting requirements create the impression that landfills create fewer CO_2 emissions than waste-to-energy operations, when this is far from true. Both landfills and waste-to-energy operations perform the vital municipal function of solid waste disposal, yet landfills benefit from CO_2 reporting obligations that create the impression that they produce less greenhouse gas. This disparity in reporting creates the inaccurate impression that replacing waste-to-energy operations with landfills would result in a net reduction in CO_2 emissions, but this is not the case. The disparity in reporting obligations does not serve the purpose of the Climate Commitment Act as it inaccurately accounts for total CO_2 emissions at similarly situated solid waste disposal facilities.

To correct this disparity, disposal of solid waste at waste-to-energy operations should be categorized and emissions reported consistent with other solid waste disposal options. The Proposed Rule should recognize waste-to-energy operations as necessary waste management facilities, just as it does for landfills; both provide essentially the same critical service.

To that end, the Proposed Rule should provide flexibility for Washington's only waste-to-energy operation to enter the program on the same basis as landfills, i.e., at the start of the 3rd compliance period, and

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[32] *In the Matter of the Petition of City of Spokane*, Declaratory Order, Docket UE-210247 ¶ 28 (July 23, 2021 W.U.T.C.) (finding that the actual operation of the plant in recent years was a meaningful indicator of the plant's intended use).

[33] *See* WAC 173-441-050(3).

[34] *See* WAC 173-441-120(1); 40 C.F.R. § 98.342.

should also be included in Ecology's greenhouse gas reduction policy discussed in Section 10(3)(c) of the Act.

While the Climate Commitment Act identifies waste-to-energy operations as having an earlier compliance period, the text of that portion of the Act indicates that it should be applied to waste-to-energy operations that have a *primary* function of energy generation.[35] The Climate Commitment Act states that the second compliance period is applicable to waste-to-energy operations where "a waste to energy facility [is] utilized by a county and city solid waste management program." Here, as established by the UTC, the WTEF *is* a waste disposal facility that produces energy as an ancillary function. The primary function is waste disposal on par with a landfill.

Establishing parity between landfills and waste-to-energy operations would allow time for innovative research and improvements in waste-to-energy technology to develop without unduly pressuring operations like WTEF to close. The potential for the waste-to-energy industry to provide even greater benefits in the areas of sustainability and energy management has been recognized by the U.S. Department of Energy ("DOE"). In late 2019, DOE kicked off two programs within their Advances Research Projects Agency-Energy group. The programs, called Monetizing Innovative Disposal Applications and Solutions ("MIDAS") and Waste to X ("WIX"), aim to derive value and reduce waste.[36] Universities and companies across the nation have received funding and are working projects using MIDAS and WIX funding.

As mentioned previously, universities and the private sector are developing innovative projects to enhance metal recovery from ash generated by waste-to-energy operations, while also developing additional carbon capture technologies. Furthermore, these entities are also working on developing novel compounds that can produce useful industrial materials while reducing carbon emissions. The City partners with these researchers and developers because it is committed to pursuing technological advancement and innovation in the waste-to-energy industry. Closure of the WTEF would result in fewer opportunities to develop advanced technology that further enhances the ability of waste-to-energy operations to minimize greenhouse gas emissions.

Instead of penalizing innovation, the Proposed Rule should include provisions that encourage research and development and provide time and flexibility for the waste-to-energy industry to realize its full potential for greenhouse gas emission reduction.

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[35] *See* Climate Commitment Act § 10(2) (identifying applicability of the compliance period "where the person owns or operates a waste to energy facility utilized by a county and city solid waste management program").

[36] *See* ARPA-E, *Waste Into X and the MIDAS Touch* (Oct. 5, 2020), https://arpa-e.energy.gov/news-and-media/blog-posts/waste-x-and-midas-touch.

c. The Proposed Rule Should Provide Credit or Accounting/Allowances for Waste-To-Energy Avoided Emissions

The Proposed Rule should provide specific accounting or allowances for emissions avoided by waste-to-energy operations when compared to those produced by landfills. Direct emission from a waste-to-energy operation is an inappropriate metric to calculate greenhouse gases. Waste-to-energy operations have significantly reduced lifecycle emissions when compared to landfills, although the two operations perform identical municipal functions. As currently drafted, the Proposed Rule does not allow the WTEF to account for avoided greenhouse gas emissions and other environmental benefits that are generated by avoiding landfilling. These benefits include:

- lower transportation emissions - approximately 75% reduction in greenhouse gas emissions from waste transportation;
- metal recovery - avoidance of emissions associated with metal production from virgin ore by recovery of over 9,000 tons of ferrous metals from solid waste annually, avoiding the need for use of virgin/raw materials (and the mining activities associated with these materials); and,
- avoidance of fossil fuel - generating energy from municipal waste reduces fossil fuel emissions from electricity generation.

Without a mechanism to account for avoided emissions, the WTEF will be unfairly penalized under a program that is intended to promote innovation and minimize lifecycle emissions.

One potential mechanism to remedy this oversight would be to provide a rule exemption similar to that granted for landfills. Per proposed WAC 173-446-030(3), a landfill that meets the following requirements are not subject to the rule: a landfill that captures at least 75 percent of the landfill gas generated by the decomposition of waste as reported under Chapter 173-441 WAC; and that operates a program that results in the production of renewable natural gas or electricity from landfill gas generated by the facility.

Similarly, waste-to-energy operations should be offered a mechanism by which lifecycle emissions avoided through the waste-to-energy process can be credited back to the facility to account for the actual total lifecycle emissions implicated in the waste-to-energy process. These credits should also take account of the significant level of methane emissions avoided through the generation of energy compared to landfilling. These credits should similarly balance the emissions avoided by disposing of waste in the jurisdiction in which it was generated and collected, rather than transporting it to landfills located hundreds of miles away. Finally, the credits should take into account the significant lifecycle emissions avoided through the recovery and recycling of ferrous and nonferrous metals that occur at waste-to-energy operations.

III. Conclusion

The City respectfully submits these comments to Ecology in the interest of adoption of a final rule that reflects the underlying principles of the Climate Commitment Act, and that fairly and equitably treats solid waste disposal facilities. The final rule needs to provide consistency and parity among the covered sources as outlined and discussed above. The WTEF has a proven track record: it is an environmentally responsible solution for solid waste management that minimizes greenhouse gases and can easily promote waste management innovation, in addition to numerous other benefits, when compared to more traditional methods, such as landfills.[37] The Proposed Rule should acknowledge and incorporate the innovative science of solid waste management by incorporating the many environmental benefits provided by WTEF into its emissions calculations.

Thank you for the opportunity to offer these comments on the proposed rule changes. The City of Spokane remains committed to protecting and improving our environment and working with Ecology for the health of our community, state, and beyond. Please do not hesitate to contact me should you have any questions or would like more information.

Sincerely,

Marlene C Feist

Marlene Feist
Public Works Director

Enc: 1) *Is it Better to Burn or Bury Waste for Clean Electricity Generation*
2) *A Solution to Man-made Methane*
3) *America's Need for Clean, Renewable Energy: - THE CASE FOR WASTE-TO-ENERGY*
4) *Scientific Truth About Waste-to-Energy*

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[37] *See, e.g.*, America's Need for Clean, Renewable Energy: THE CASE FOR WASTE-TO-ENERGY.

ENCLOSURE 1

Policy Analysis

Is It Better To Burn or Bury Waste for Clean Electricity Generation?

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Environ. Sci. Technol., **2009**, 43 (6), 1711-1717• DOI: 10.1021/es802395e • Publication Date (Web): 10 February 2009

Environmental Science & Technology is published by the American Chemical Society. 1155 Sixteenth Street N.W., Washington, DC 20036

Environ. Sci. Technol. **2009,** *43,* 1711–1717

Is It Better To Burn or Bury Waste for Clean Electricity Generation?

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Received August 26, 2008. Revised manuscript received December 13, 2008. Accepted December 30, 2008.

The use of municipal solid waste (MSW) to generate electricity through landfill-gas-to-energy (LFGTE) and waste-to-energy (WTE) projects represents roughly 14% of U.S. nonhydro renewable electricity generation. Although various aspects of LFGTE and WTE have been analyzed in the literature, this paper is the first to present a comprehensive set of life-cycle emission factors per unit of electricity generated for these energy recovery options. In addition, sensitivity analysis is conducted on key inputs (e.g., efficiency of the WTE plant, landfill gas management schedules, oxidation rate, and waste composition) to quantify the variability in the resultant life-cycle emissions estimates. While methane from landfills results from the anaerobic breakdown of biogenic materials, the energy derived from WTE results from the combustion of both biogenic and fossil materials. The greenhouse gas emissions for WTE ranges from 0.4 to 1.5 MTCO$_2$e/MWh, whereas the most agressive LFGTE scenerio results in 2.3 MTCO$_2$e/MWh. WTE also produces lower NO$_x$ emissions than LFGTE, whereas SO$_x$ emissions depend on the specific configurations of WTE and LFGTE.

Introduction

In response to increasing public concern over air pollution and climate change, the use of renewable energy for electricity generation has grown steadily over the past few decades. Between 2002 and 2006, U.S. renewable electricity generation—as a percent of total generation—grew an average of 5% annually (*1*), while total electricity supply grew by only 1% on average (*2*). Support mechanisms contributing to the growth of renewables in the United States include corporate partnership programs, investment tax credits, renewable portfolio standards, and green power markets. These mechanisms provide electric utilities, investment firms, corporations, governments, and private citizens with a variety of ways to support renewable energy development. With several competing renewable alternatives, investment and purchasing decisions should be informed, at least in part, by rigorous life-cycle assessment (LCA).

In 2005, a total of 245 million tons of MSW was generated in the United States, with 166 million tons discarded to landfills (*3*). Despite the increase in recycling and composting rates, the quantity of waste disposed to landfills is still significant and expected to increase. How to best manage the discarded portion of the waste remains an important consideration, particularly given the electricity generation options. Although less prominent than solar and wind, the use of municipal solid waste (MSW) to generate electricity represents roughly 14% of U.S. nonhydro renewable electricity generation (*1*). In this paper we compare two options for generating electricity from MSW. One method, referred to as landfill-gas-to-energy (LFGTE), involves the collection of landfill gas (LFG) (50% CH$_4$ and 50% CO$_2$), which is generated through the anaerobic decomposition of MSW in landfills. The collected LFG is then combusted in an engine or a turbine to generate electricity. A second method, referred to as waste-to-energy (WTE) involves the direct combustion of MSW, where the resultant steam is used to run a turbine and electric generator.

Clean Air Act (CAA) regulations require capture and control of LFG from large landfills by installing a gas collection system within 5 years of waste placement (*4*). The gas collection system is expanded to newer areas of the landfill as more waste is buried. Not all LFG is collected due to delays in gas collection from initial waste placement and leaks in the header pipes, extraction wells, and cover material. Collected gas can be either flared or utilized for energy recovery. As of 2005, there were 427 landfills out of 1654 municipal landfills in the United States with LFGTE projects for a total capacity of 1260 MW. It is difficult to quantify emissions with a high degree of certainty since emissions result from biological processes that can be difficult to predict, occur over multiple decades, and are distributed over a relatively large area covered by the landfill.

CAA regulations require that all WTE facilities have the latest in air pollution control equipment (*5*). Performance data including annual stack tests and continuous emission monitoring are available for all 87 WTE plants operating in 25 states. Since the early development of this technology, there have been major improvements in stack gas emissions controls for both criteria and metal emissions. The performance data indicate that actual emissions are less than regulatory requirements. Mass burn is the most common and established technology in use, though various MSW combustion technologies are described in ref *6*. All WTE facilities in the United States recover heat from the combustion process to run a steam turbine and electricity generator.

Policy-makers appear hesitant to support new WTE through new incentives and regulation. Of the 30 states that have state-wide renewable portfolio standards, all include landfill gas as an eligible resource, but only 19 include waste-to-energy (*7*). While subjective judgments almost certainly play a role in the preference for LFGTE over WTE, there is a legitimate concern about the renewability of waste-to-energy. While the production of methane in landfills is the result of the anaerobic breakdown of biogenic materials, a significant fraction of the energy derived from WTE results from combusting fossil-fuel-derived materials, such as plastics. Countering this effect, however, is significant methane leakage—ranging from 60% to 85%—from landfills (*8*). Since methane has a global warming potential of 21 times that of CO$_2$, the CO$_2$e emissions from LFGTE may be larger than those from WTE despite the difference in biogenic composition.

Although WTE and LFGTE are widely deployed and analyzed in the literature (*9*–*13*), side-by-side comparison of the life-cycle inventory (LCI) emission estimates on a mass

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10.1021/es802395e CCC: $40.75

per unit energy basis is unavailable. LCI-based methods have been used to evaluate and compare solid waste management (SWM) unit operations and systems holistically to quantify either the environmental impacts or energy use associated with SWM options in the broad context of MSW management (*14–16*).

The purpose of this paper is to present a comprehensive set of life-cycle emission factors—per unit of electricity generated—for LFGTE and WTE. In addition, these emission factors are referenced to baseline scenarios without energy recovery to enable comparison of the emissions of LFGTE and WTE to those of other energy sources. While the methodology presented here is applicable to any country, this analysis is based on U.S. waste composition, handling, and disposal, with which the authors are most familiar. In addition, parametric sensitivity analysis is applied to key input parameters to draw robust conclusions regarding the emissions from LFGTE and WTE. The resultant emission factors provide critical data that can inform the development of renewable energy policies as well as purchasing and investment decisions for renewable energy projects in the prevailing marketplace.

Modeling Framework

The LFGTE and WTE emission factors are based on the composition and quantity of MSW discarded in the United States in 2005 (Table S1 of Supporting Information (SI)). We excluded the estimated quantity and composition of recycled and composted waste.

The emission factors are generated using the life-cycle-based process models for WTE (*17*) and LF/LFGTE (*18*) embedded in the municipal solid waste decision support tool (MSW-DST). The MSW-DST was developed through a competed cooperative agreement between EPA's Office of Research and Development and RTI International (*19–22*). The research team included North Carolina State University, which had a major role in the development of the LCI database, process, and cost models as well as the prototype MSW-DST. While a summary is provided here, Table S2 (SI) provides a comprehensive set of references for those interested in particular model details. The MSW-DST includes a number of process models that represent the operation of each SWM unit and all associated processes for collection, sorting, processing, transport, and disposal of waste. In addition, there are process models to account for the emissions associated with the production and consumption of gasoline and electricity. The objective of each process model is to relate the quantity and composition of waste entering a process to the cost and LCI of emissions for that process. The LCI emissions are calculated on the basis of a combination of default LCI data and user-input data to enable the user to model a site-specific system. For example, in the landfill process model, one key exogenous input is the efficiency of the LFG collection system. The functional unit in each process model is 1 ton of MSW set out for collection. The MSW includes the nonhazardous solid waste generated in residential, commercial, institutional, and industrial sectors (*3*).

Each process model can track 32 life-cycle parameters, including energy consumption, CO_2, CO, NO_x, SO_x, total greenhouse gases (CO_2e), particulate matter (PM), CH_4, water pollutants, and solid wastes. CO_2 emissions are represented in two forms: fossil and biogenic. CO_2 released from anthropogenic activities such as burning fossil fuels or fossil-fuel-derived products (e.g., plastics) for electricity generation and transportation are categorized as CO_2-fossil. Likewise, CO_2 released during natural processes such as the decay of paper in landfills is categorized as CO_2-biogenic.

The management of MSW will always result in additional emissions due to collection, transportation, and separation of waste. However, for this analysis, the configuration of the SWM system up through the delivery of the waste to either a landfill or WTE facility is assumed to be same.

TABLE 1. Inputs to the Landfill Process Model

	LFG collection system efficiency [a] (%)	oxidation rate (%)
during venting	0	15
during first year of gas collection	50	15
during second year of gas collection	70	15
during third year and on of gas collection	80	15

[a] We assumed efficiency of the collection system based on the year of the operation and the ranges stated in U.S. EPA's AP-42 (*8*).

Electricity Grids. While LFGTE and WTE provide emissions reductions relative to landfill scenarios without energy recovery, the generation of electricity from these sources also displaces conventional generating units on the electricity grid. The process models in MSW-DST can calculate total electricity generated and apply an offset analysis on the grid mix of fuels specific to each of the North American Electric Reliability Council (NERC) regions, an average national grid mix, or a user-defined grid mix. Because our focus is on the emissions differences between WTE and LFGTE technologies, the emissions factors reported here exclude the displaced grid emissions.

For reference purposes, emission factors for conventional electricity-generating technologies are reported along with the emission factors for WTE and LFGTE (*23*). These emission factors on a per megawatt hour basis include both the operating emissions from power plants with postcombustion air pollution control equipment and precombustion emissions due to extraction, processing, and transportation of fuel. The background LCI data are collected on a unit mass of fuel (*23*); when converted on a per unit of electricity generated basis, the magnitude of resultant emissions depends on the efficiency of the power plant. A sensitivity analysis was conducted on plant efficiencies to provide ranges for emission factors.

Estimating Emission Factors for Landfill Gas-to-Energy. The total LCI emissions from landfills are the summation of the emissions resulting from (1) the site preparation, operation, and postclosure operation of a landfill, (2) the decay of the waste under anaerobic conditions, (3) the equipment utilized during landfill operations and landfill gas management operations, (4) the production of diesel required to operate the vehicles at the site, and (5) the treatment of leachate (*18*). The production of LFG was calculated using a first-order decay equation for a given time horizon of 100 years and the empirical methane yield from each individual waste component (*18, 24*). Other model inputs include the quantity and the composition of waste disposed (Table S1, SI), LFG collection efficiency (Table 1), annual LFG management schedule (Figure 1), oxidation rate (Table 1), emission factors for combustion byproduct from LFG control devices (Table S3, SI), and emission factors for equipment used on site during the site preparation and operation of a landfill. While there are hundreds of inputs to the process models, we have modified and conducted sensitivity analysis on the input parameters that will affect the emission factors most significantly.

The emission factors are calculated under the following scenario assumptions: (1) A regional landfill subject to CAA is considered. (2) A single cell in the regional landfill is modeled. (3) Waste is initially placed in the new cell in year 0. (4) The landfill already has an LFG collection network in place. (5) An internal combustion engine (ICE) is utilized to generate electricity. (6) The offline time that is required for

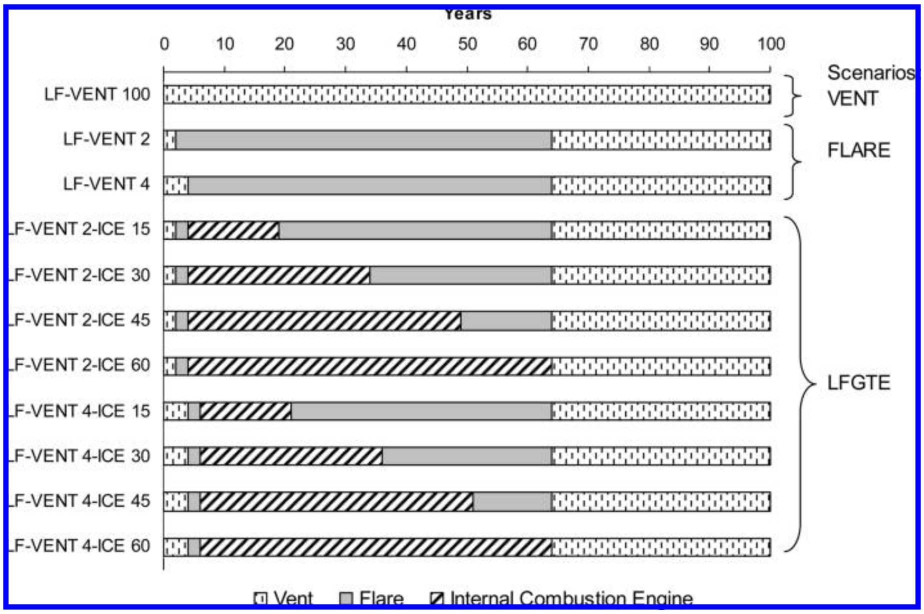

FIGURE 1. Annual landfill gas management schedule assumed for alternative scenarios.

the routine maintenance of the ICE is not considered. (7) The LFG control devices are assumed to have a lifetime of 15 years. (8) The LFG will be collected and controlled until year 65. This assumption is based on a typical landfill with an average operating lifetime of 20 years in which LFG production decreases significantly after about 60 years from initial waste placement. This is based on the use of a first-order decay equation utilizing empirical data from about 50 U.S. LFG collection systems.

The timing of LFG-related operations has significant variation and uncertainty that will influence the total emissions from landfills as well as the emission factors per unit of electricity generated. To capture these uncertainties and variation, several different management schemes were tested. Figure 1 presents the different cases considered for LFGTE projects. Each case differs according to the management timeline of the LFG. For instance, LF-VENT 2-ICE 15 corresponds to no controls on LFG for the first two years, after which the LFG is collected and flared in the third and fourth years. From year 5 until year 19, for a period of 15 years, the LFG is processed through an ICE to generate electricity, after which the collected gas is flared until year 65. Finally from year 65 on, the LFG is released to the atmosphere without controls.

To quantify the emissions benefit from LFGTE and WTE, landfill emissions occurring in the absence of an energy recovery unit can serve as a useful comparison. Thus, three baseline scenarios without electricity generation were defined for comparison to the energy recovery scenarios: LF-VENT 100 (LFG is uncontrolled for the entire lifetime of the LF), LF-VENT 2 (LFG is uncontrolled for the first two years, and then the LFG is collected and flared until year 65), LF-VENT 4 (LFG is uncontrolled for the first four years, and then the LFG is collected and flared until year 65). Since emissions are normalized by the amount of electricity generated (MW h) to obtain the emission rates, an estimate of hypothetical electricity generation for the baseline scenarios must be defined. The average electricity generation from a subset of the energy recovery scenarios is used to calculate the baseline emission rates. For example, emission factors [g/(MW h)] for LF-VENT 2 are based on the average of electricity generated in LF-VENT 2-ICE 15, LF-VENT 2-ICE 30, LF-VENT 2-ICE 45, and LF-VENT 2-ICE 60. Additional sensitivity analysis was conducted on oxidation rates where scenarios were tested for a range of 10−35%.

Estimating Emission Factors for Waste-to-Energy. The total LCI emissions are the summation of the emissions associated with (1) the combustion of waste (i.e., the stack gas (accounting for controls)), (2) the production and use of limestone in the control technologies (i.e., scrubbers), and (3) the disposal of ash in a landfill (*17*).

Emissions associated with the manufacture of equipment such as turbines and boilers for the WTE facility are found to be insignificant (<5% of the overall LCI burdens) and, as a result, were excluded from this analysis (*25*). In addition, WTE facilities have the capability to recover ferrous material from the incoming waste stream and also from bottom ash with up to a 90% recovery rate. The recovered metal displaces the virgin ferrous material used in the manufacturing of steel. The emission offsets from this activity could be significant depending on the amount of ferrous material recovered. Total LCI emissions for WTE were presented without the ferrous offsets; however, sensitivity analysis was conducted to investigate the significance.

In the United States, federal regulations set limits on the maximum allowable concentration of criteria pollutants and some metals from MSW combustors (*5*). The LCI model calculates the controlled stack emissions using either the average concentration values at current WTE facilities based on field data or mass emission limits based on regulatory requirements as upper bound constraints. Two sets of concentration values (Table S4, SI) are used in calculations to report two sets of emission factors for WTE (i.e., WTE-Reg and WTE-Avg). The emission factors for WTE-Reg were based on the regulatory concentration limits (*5*), whereas the emission factors for WTE-Avg were based on the average concentrations at current WTE facilities.

The CO_2 emissions were calculated using basic carbon stoichiometry given the quantity, moisture, and ultimate analysis of individual waste items in the waste stream. The LCI model outputs the total megawatt hour of electricity production and emissions that are generated per unit mass of each waste item. The amount of electricity output is a function of the quantity, energy, and moisture content of the individual waste items in the stream (Table S1, Supporting Information), and the system efficiency. A lifetime of 20 years and a system efficiency of 19% [18000 Btu/(kW h)] were assumed for the WTE scenarios. For each pollutant, the following equation was computed:

$$\mathrm{LCI\_WTE}_i = \sum_j \{(\mathrm{LCI\_Stack}_{ij} + \mathrm{LCI\_Limestone}_{ij} + \mathrm{LCI\_Ash}_{ij}) \times \mathrm{Mass}_j\}/\mathrm{Elec} \quad \text{for all } i \quad (1)$$

where $\mathrm{LCI\_WTE}_i$ is the LCI emission factor for pollutant i [g/(MW h)], $\mathrm{LCI\_Stack}_{ij}$ is the controlled stack gas emissions for pollutant i (g/ton of waste item j), $\mathrm{LCI\_Limestone}_{ij}$ is the allocated emissions of pollutant i from the production and use of limestone in the scrubbers (g/ton of waste item j), $\mathrm{LCI\_Ash}_{ij}$ is the allocated emissions of pollutant i from the disposal of ash (g/ton of waste item j), Mass_j is the amount of each waste item j processed in the facility (ton), and Elec is the total electricity generated from MSW processed in the facility (MW h). In addition, the sensitivity of emission factors to the system efficiency, the fossil and biogenic fractions of MSW, and the remanufacturing offsets from steel recovery was quantified.

Results and Discussion

The LCI emissions resulting from the generation of 1 MW h of electricity through LFGTE and WTE as well as coal, natural gas, oil, and nuclear power (for comparative purposes) were calculated. The sensitivity of emission factors to various inputs was analyzed and is reported. Figures 2−4 summarize the emission factors for total CO_2e, SO_x, and NO_x, respectively.

Landfills are a major source of CH_4 emissions, whereas WTE, coal, natural gas, and oil are major sources of CO_2-fossil emissions (Table S5, SI). The magnitude of CH_4 emissions strongly depends on when the LFG collection system is installed and how long the ICE is used. For example, LF-VENT 2-ICE 60 has the least methane emissions among LFGTE alternatives because the ICE is operated the longest (Table S5, SI). CO_2e emissions from landfills were significantly higher than the emissions for other alternatives because of the relatively high methane emissions (Figure 2, Table S5).

The use of LFG control during operation, closure, and postclosure of the landfill as well as the treatment of leachate contributes to the SO_x emissions from landfills. SO_x emissions from WTE facilities occur during the combustion process and are controlled via wet or dry scrubbers. Overall, the SO_x emissions resulting from the LFGTE and WTE alternatives are approximately 10 times lower than the SO_x emissions resulting from coal- and oil-fired power plants with flue gas controls (Figure 3). The SO_x emissions for WTE ranged from 140 to 730 g/(MW h), and for LFGTE they ranged from 430 to 900 g/(MW h) (Table 2, Table S5). In a coal-fired power plant, average SO_x emissions were 6900 g/(MW h) (Table S6 and S7, SI). Another important observation is that the majority of the SO_x emissions from natural gas are attributed to processing of natural gas rather than the combustion of the natural gas for electricity-generating purposes.

The NO_x emissions for WTE alternatives ranged from 810 to 1800 g/(MW h), and for LFGTE they ranged from 2100 to 3000 g/(MW h) (Figure 4, Table 2, Table S5). In a coal-fired power plant, average NO_x emissions are 3700 g/(MW h) (Tables S6 and S7, Supporting Information). The emission factors for other criteria pollutants were also calculated. Besides CO and HCl emissions, the emission factors for all LFGTE and WTE cases are lower than those for the coal-fired generators (Tables S5−S8, SI).

While we have provided a detailed, side-by-side comparison of life-cycle emissions from LFGTE and WTE, there is an important remaining question about scale: How big an impact can energy recovery from MSW make if all of the discarded MSW (166 million tons/year) is utilized? Hypothetically, if 166 million tons of MSW is discarded in regional landfills, energy recovery on average of ~10 TW h or ~65 (kW h)/ton of MSW of electricity can be generated, whereas a WTE facility can generate on average ~100 TW h or ~600 (kW h)/ton of MSW of electricity with the same amount of MSW (Table 3). WTE can generate an order of magnitude more electricity than LFGTE given the same amount of waste. LFGTE projects would result in significantly lower electricity generation because only the biodegradable portion of the MSW contributes to LFG generation, and there are significant inefficiencies in the gas collection system that affect the quantity and quality of the LFG.

Moreover, if all MSW (excluding the recycled and composted portion) is utilized for electricity generation, the WTE alternative could have a generation capacity of 14000 MW, which could potentially replace ~4.5% of the 313000 MW of current coal-fired generation capacity (*26*).

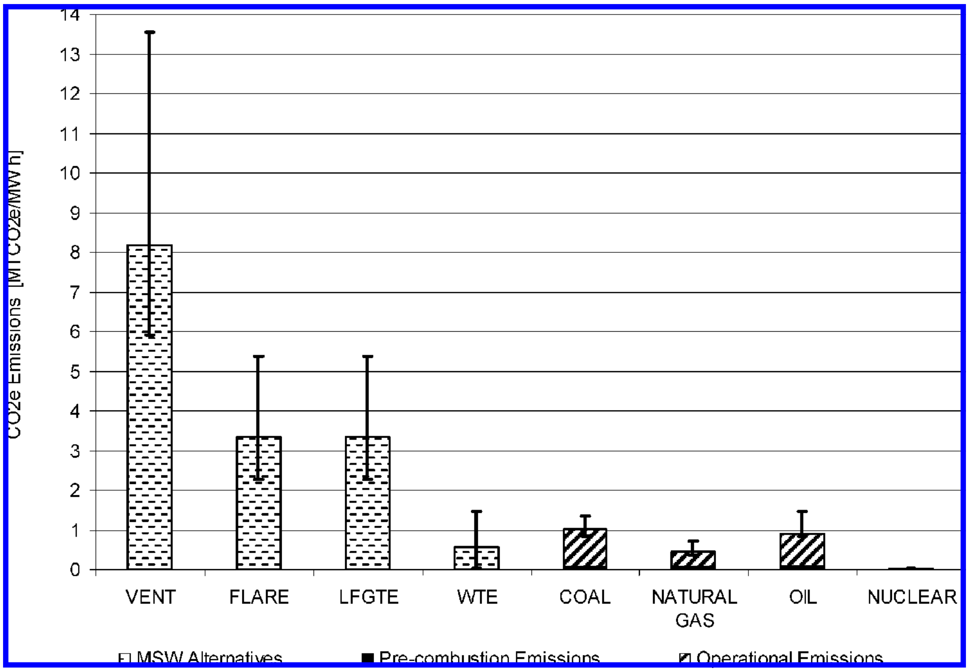

FIGURE 2. Comparison of carbon dioxide equivalents for LFGTE, WTE, and conventional electricity-generating technologies (Tables S5−S8, Supporting Information, include the full data set).

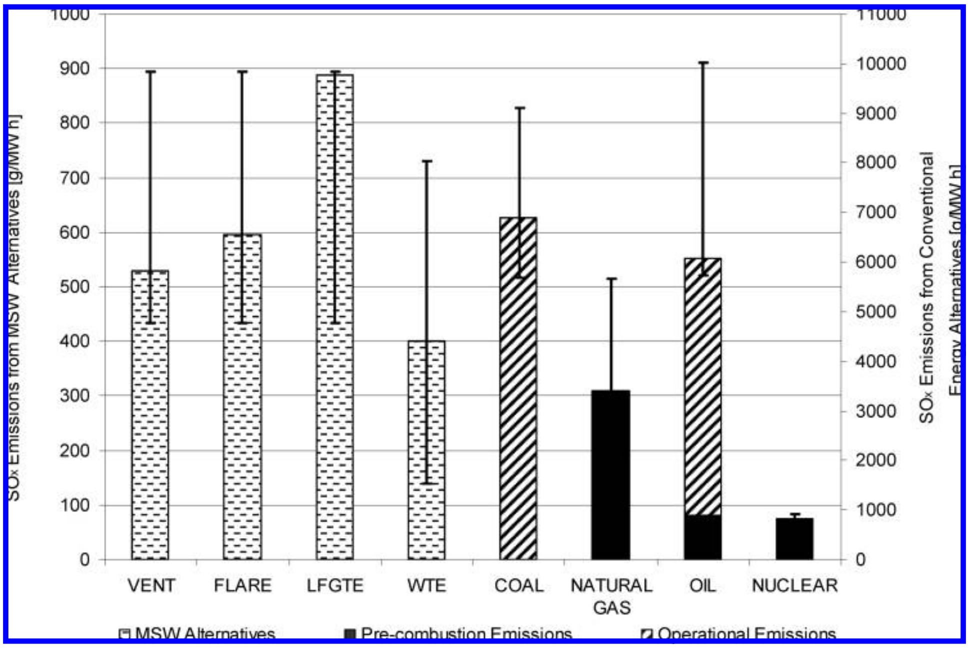

FIGURE 3. Comparison of sulfur oxide emissions for LFGTE, WTE, and conventional electricity-generating technologies (Tables S5−S8, Supporting Information, include the full data set).

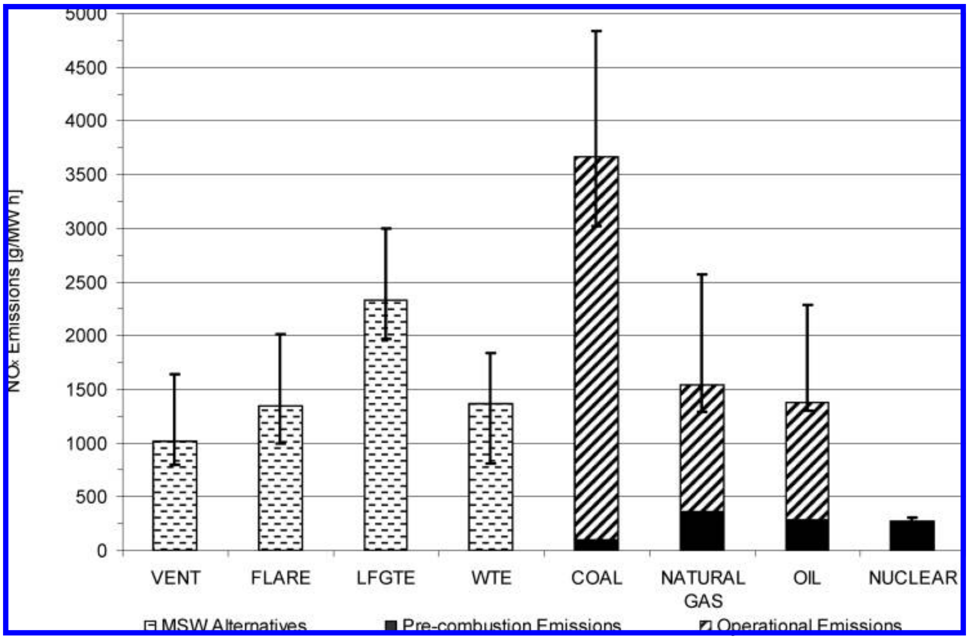

FIGURE 4. Comparison of nitrogen oxide emissions for LFGTE, WTE, and conventional electricity-generating technologies (Tables S5−S8, Supporting Information, include the full data set).

A significant portion of this capacity could be achieved through centralized facilities where waste is transported from greater distances. The transportation of waste could result in additional environmental burdens, and there are clearly limitations in accessing all discarded MSW in the nation. Wanichpongpan studied the LFGTE option for Thailand and found that large centralized landfills with energy recovery performed much better in terms of cost and GHG emissions than small, localized landfills despite the increased burdens associated with transportation (*13*). To quantify these burdens for the United States, emission factors were also calculated for long hauling of the waste via freight or rail. Table S9 (SI) summarizes the emission factors for transporting 1 ton of MSW to a facility by heavy-duty trucks and rail.

Sensitivity analysis was also conducted on key inputs. With incremental improvements, WTE facilities could achieve efficiencies that are closer to those of conventional power plants. Thus, the system efficiency was varied from 15% to 30%, and Table 2 summarizes the resulting LCI emissions. The variation in efficiencies results in a range of 470−930 kW h of electricity/ton of MSW, while with the default heat rate; only 600 (kW h)/ton of MSW can be generated. The efficiency also affects the emission factors; for example, CO_2-fossil emissions vary from 0.36 to 0.71 Mg/(MW h).

The emission savings associated with ferrous recovery decreased the CO_2e emissions of the WTE-Reg case from 0.56 to 0.49 $MTCO_2e$/(MW h). Significant reductions were observed for CO and PM emissions (Table 2).

TABLE 2. Sensitivity of Emission Factors for WTE to Plant Efficiency, Waste Composition, and Remanufacturing Benefits of Steel Recovery

			Sensitivity on				
	baseline factors		system efficiency	waste composition		steel recovery	
			Input Parameters Varied[a]				
heat rate [Btu/(kW h)]	18000	18000	*[11000, 23000]*	18000	18000	18000	18000
efficiency (%)	19	19	*[15, 30]*	19	19	19	19
composition	default	default	default	*all biogenic*	*all fossil*	default	default
stack gas limits	reg	avg	*reg/avg*	reg	reg	*reg*	*avg*
steel recovery	excludes	excludes	excludes	excludes	excludes	*includes*	*includes*
			Results: Criteria Pollutants				
CO [g/(MW h)]	790	790	[500,1000]	740	880	−110	−110
NO_x [g/(MW h)]	1300	1500	[810, 1800]	1200	1400	1200	1400
SO_x [g/(MW h)]	578	221	[140, 730]	550	620	450	90
PM [g/(MW h)]	181	60	[38, 230]	180	190	−190	−310
			Results: Greenhouse Gases				
CO_2-biogenic [Mg/(MW h)]	0.91	0.91	[0.58, 1.2]	1.5	0.03	0.91	0.91
CO_2-fossil [Mg/(MW h)]	0.56	0.56	[0.36, 0.71]	0.02	1.5	0.49	0.49
CH_4 [Mg/(MW h)]	1.3E−05	1.3E−05	[8.1E−06, 1.6E−05]	1.6E−05	7.9E−06	−5.0E−05	−5.0E−05
CO_2e [$MTCO_2e$/(MW h)]	0.56	0.56	[0.36, 0.71]	0.02	1.45	0.49	0.49
			Results: Electricity Generation				
TW h [b]	98	98	[78, 160]	61	37	98	98
(kW h)/ton	590	590	[470, 930]	470	970	590	590
GW [c]	12	12	[9.7, 20]	7.6	4.7	12	12

[a] For each sensitivity analysis scenario, the input parameters in italics were modified and resultant emission factors were calculated and are reported. [b] The values represent the TWh of electricity that could be generated from all MSW disposed into landfills. [c] 1 TWh/8000 h = TW; a capacity factor of approximately 0.91 was utilized.

TABLE 3. Comparison of Total Power Generated

	total electricity generated from 166 million tons of MSW, TW h	total power [a], GW	electricity generated from 1 ton of MSW, (kW h)/ton
waste-to-energy	78−160	9.7−19	470−930
landfill-gas-to-energy	7−14	0.85−1.8	41−84

[a] 1 TW h/8000 h = TW; a capacity factor of approximately 0.91 was utilized.

The composition of MSW also has an effect on the emission factors. One of the controversial aspects of WTE is the fossil-based content of MSW, which contributes to the combustion emissions. The average composition of MSW as discarded by weight was calculated to be 77% biogenic- and 23% fossil-based (Table S1, SI). The sensitivity of emission factors to the biogenic- vs fossil-based waste fraction was also determined. Two compositions (one with 100% biogenic-based waste and another with 100% fossil-based waste) were used to generate the emission factors (Table 2). The CO_2e emissions from WTE increased from 0.56 $MTCO_2e$/(MW h) (WTE-Reg) to 1.5 $MTCO_2e$/(MW h) when the 100% fossil-based composition was used (Table 2, Figure 2). However, the CO_2e emissions from WTE based on 100% fossil-based waste were still lower than the most aggressive LFGTE scenario (i.e., LF-VENT 2-ICE 60) whose CO_2e emissions were 2.3 $MTCO_2e$/(MW h).

The landfill emission factors include the decay of MSW over 100 years, whereas emissions from WTE and conventional electricity-generating technologies are instantaneous. The operation and decomposition of waste in landfills continue even beyond the monitoring phases for an indefinite period of time. Reliably quantifying the landfill gas collection efficiency is difficult due to the ever-changing nature of landfills, number of decades that emissions are generated, and changes over time in landfill design and operation including waste quantity and composition. Landfills are an area source, which makes emissions more difficult to monitor. In a recent release of updated emission factors for landfill gas emissions, data were available for less than 5% of active municipal landfills (*27*). Across the United States, there are major differences in how landfills are designed and operated, which further complicates the development of reliable emission factors. This is why a range of alternative scenarios are evaluated with plausible yet optimistic assumptions for LFG control. For WTE facilities, there is less variability in the design and operation. In addition, the U.S. EPA has data for all the operating WTE facilities as a result of CAA requirements for annual stack testing of pollutants of concern, including dioxin/furan, Cd, Pb, Hg, PM, and HCl. In addition, data are available for SO_2, NO_x, and CO from continuous emissions monitoring. As a result, the quality and availability of data for WTE versus LFGTE results in a greater degree of certainty for estimating emission factors for WTE facilities.

The methane potential of biogenic waste components such as paper, food, and yard waste is measured under optimum anaerobic decay conditions in a laboratory study (*24*), whose other observations reveal that some portion of the carbon in the waste does not biodegrade and thus this quantity gets sequestered in landfills (*28*). However, there is still a debate on how to account for any biogenic "sequestered" carbon. Issues include the choice of appropriate time frame for sequestration and who should be entitled to potential sequestration credits. While important, this analysis does not assign any credits for carbon sequestered in landfills.

Despite increased recycling efforts, U.S. population growth will ensure that the portion of MSW discarded in landfills will remain significant and growing. Discarded MSW is a viable energy source for electricity generation in a carbon-constrained world. One notable difference between LFGTE and WTE is that the latter is capable of producing an order of magnitude more electricity from the same mass of waste. In addition, as demonstrated in this paper, there are significant differences in emissions on a mass per unit energy basis from LFGTE and WTE. On the basis of the assumptions in this paper, WTE appears to be a better option than LFGTE. If the goal is greenhouse gas reduction, then WTE should be considered as an option under U.S. renewable energy policies. In addition, all LFTGE scenarios tested had on the average higher NO_x, SO_x, and PM emissions than WTE. However, HCl emissions from WTE are significantly higher than the LFGTE scenarios.

Supporting Information Available

MSW composition, physical and chemical characteristics of waste items, detailed LCI tables and sensitivity results, and emission factors for long haul of MSW. This material is available free of charge via the Internet at http://pubs.acs.org.

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ENCLOSURE 2

A Solution to Man-made Methane

Reducing the release of the very potent greenhouse gas methane should be a top priority in the world's fight against climate change. This point was emphasized in a recent Wall Street Journal opinion by Fred Krupp, president of the Environmental Defense Fund. Mr. Krupp argued that reducing releases of anthropogenic methane should be an immediate focus because it would help slow the rate of near-term global warming more quickly than more expensive carbon reduction strategies. There should be no disagreement. In fact, Krupp's point can be strengthened to stress that *any* available reduction of methane will return more immediate benefit than reductions in other greenhouse gases. Leaders at the Glasgow COP26 meeting properly pledged curtailment of methane releases, focusing on regulating emissions from fossil fuel production facilities. Yet one such major source of methane, generated in vast amounts and managed poorly every day, is missing from the Glasgow discussion: garbage.

The world-wide generation of solid waste is huge and growing. The U.S. alone is approaching 300 million tons of garbage annually. Despite long-term efforts to reduce, reuse, and recycle, most of it continues to be landfilled. Once piled high in a landfill, it begins to emit methane in large quantities. Thousands of these sources have been created. Many more are on the way. Most will eventually be abandoned to sit and ooze gases. There is one solution.

Modern waste-to-energy (WTE) facilities exist world-wide. They take waste that contains carbon and convert it to energy while greatly reducing the volume of methane-generating material going to landfills. They produce highly reliable electricity for the grid and work in concert with recycling programs in every locality where they operate. Modeling has shown that for every ton of garbage processed in a WTE plant, about one ton of carbon offset is created via methane reduction, fossil fuel energy replacement, and metals recovery.

Arguments have been made that burning waste for energy to reduce carbon emissions is counter-intuitive; that it is better to work towards attaining zero waste via reduce, reuse, and recycle programs. Yet recycling rates have remained flat since 2010 and recycling markets are not improving. WTE facilities do emit CO2, but that carbon is already in our environment. Better to regain the energy in solid waste than to landfill it. A recent study by Dr. Marco Castaldi of the City College of New York addresses these points in far greater detail than can be covered here.

The answer to massive methane releases may well lie in greater regulation of industrial sources. However, until we recognize the growing impact of methane generation from our own daily consumption and disposal habits, we miss another big opportunity to lower man-made methane generation. Humans put enormous effort into producing products and materials that enhance our lives. Then, we throw much of it away. But why waste this continuously generated resource when, instead, we can significantly reduce landfilling and at the same time recover energy?

As President Biden said at the COP26 summit, "One of the most important things we can do in this decisive decade … is to reduce our methane emissions as quickly as possible."

There should be no disagreement on this.

William Brandes is a retired branch chief formerly at the U.S. EPA's Office of Solid Waste in Washington, D.C.

ENCLOSURE 3

LOCAL GOVERNMENT COALITION FOR RENEWABLE ENERGY

Barron County Waste-to-Energy
and Recycling Facility
(Almena, Wisconsin)

Bristol Resource Recovery Facility
Operating Committee
(Bristol, Connecticut)

City of Ames, Iowa

City of Harrisburg, Pennsylvania

City and County of Honolulu,
Hawaii

City of Huntsville Solid Waste
Disposal Authority
(Huntsville, Alabama)

City of Tampa, Florida

County Sanitation Districts of
Los Angeles County
(Whittier, California)

ecomaine (Portland, Maine)

Kent County, Michigan

Lancaster County Solid
Waste Management Authority
(Lancaster, Pennsylvania)

Marion County, Oregon

Mid-Maine Waste Action Corp.
(Auburn, Maine)

Northeast Maryland Waste
Disposal Authority
(Baltimore, Maryland)

Pollution Control Financing
Authority of Camden County
(Camden, New Jersey)

Solid Waste Authority of
Palm Beach County
(Palm Beach, Florida)

Spokane Regional Solid Waste
System (Spokane, Washington)

Wasatch Integrated Waste
Management District
(Layton, Utah)

York County Solid Waste Authority
(York, Pennsylvania)

** In coordination with the*
U.S. Conference of Mayors/
Municipal Waste
Management Association

America's Need for Clean, Renewable Energy:
THE CASE FOR WASTE-TO-ENERGY

- ► Waste-to-energy (WTE) is one of the most environmentally protective sources of renewable energy.
- ► In fact, the World Economic Forum's report, *Green Investing – Towards a Clean Energy Infrastructure*, recognizes **WTE as one of eight "key renewable energy sectors" and "particularly promising in terms of . . . abatement potential" for carbon emissions**. Attachment ("Att.") 1, p. 27 (for the reader's convenience, many of the sources cited here are reproduced in the Appendix).
- ► Nevertheless, WTE is a largely untapped resource in the United States – only 7% of our municipal solid waste (MSW) is directed to WTE while 69% is landfilled.[1]
- ► But as the former Chief of EPA's Energy Recovery Branch emphasized, "[i]f you want to have an impact on greenhouse gas mitigation, focus on MSW." Att. 2, slide 19 (keynote address, North American Waste-to-Energy Conference, May 18, 2009).

***Here are the facts*:**

WTE HELPS MITIGATE CLIMATE CHANGE – WTE's role in reducing greenhouse gas (GHG) emissions is widely recognized:

- As EPA's solid waste management planning methodology recognizes, WTE reduces GHG emissions in 3 ways by (i) generating electricity and/or steam without having to use fossil fuel sources, (ii) avoiding the potential methane emissions that would result if the same waste was landfilled, and (iii) recovering ferrous and nonferrous metals, which avoids the additional energy consumption that would be required if the same metals were produced from virgin ores. Att. 3, pp. 1711-14; *see also* Att. 4, Part B, Summary and pp. B-23 to B-32.
- In fact, EPA's key model for determining the life-cycle GHG emissions from alternative MSW management methods shows that one ton of GHGs is avoided for every ton of MSW that is directed to WTE rather than landfilled. http://www.epa.gov/epawaste/nonhaz/municipal/wte/airem.htm (scroll to "Greenhouse Gases").
- Consistent with EPA's analysis, the Intergovernmental Panel on Climate Change (IPCC), a leading forum of independent scientific experts on climate change, **emphasizes WTE's dual benefits of (i) offsetting fossil fuel combustion and (ii) avoided landfill methane emissions**. Att. 5, p. 601.
- Similarly, the Kyoto Protocol's Clean Development Mechanism **approves WTE as a source of tradeable GHG emission reduction credits that displaces electricity from fossil fuels and avoids landfill methane emissions**. Att. 6, pp 1-3.

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- In addition, the United Nations' recent (November 2011) report, *Bridging the Emissions Gap*, concludes that waste sector GHG emissions can be reduced 80% if there is significant diversion of currently landfilled waste to WTE. *See* http://www.unep.org/publications/ebooks/bridgingemissionsgap/ (select "Full Report"), pp. 37-38.
- Finally, the former Chief of EPA's Energy Recovery Branch referred to an evolving "best integrated material management strategy" of 45% recycling, 10% landfilling and **45% WTE**. Att. 2, slide 30. But even at the 23% WTE rate the EU15 has achieved (and EU reliance on WTE continues to increase),[2] the additional reduction in CO_2e emissions in the U.S. would be 43.2 million tons, **which is equivalent to removing more than 8 million passenger cars from the nation's roads**.[3]

MODERN WTE FACILITIES – TRUE "GREEN" TECHNOLOGY – In addition to its benefits in reducing GHGs, WTE's status as a very clean and efficient energy source is evident on many other bases:

- Reflecting state and federal requirements for the most advanced emissions control technology, WTE emissions have plummeted since the late 1980's (e.g., annual WTE emissions of dioxin have decreased by a factor of 1,000 to less than 12 grams), Att. 7, p. 1722, and WTE emissions are lower than landfill emissions for 9 of 10 major air pollutants, Att. 4, p. B-30.
- In fact, EPA analysis shows that **WTE yields the best results (compared to landfills) in terms of maximum energy recovery and lowest GHG and criteria pollutant emissions**. Att. 3, pp. 1711-14, 1716-17.
- As a result, USEPA recognizes WTE as a renewable energy source that "produce[s] 2800 megawatts of electricity with **less environmental impact than almost any other source of electricity**."[4]
- EPA's hierarchy for "integrated waste management" **recommends waste combustion with energy recovery over landfilling** (as does the European Union).[5]
- WTE's efficiency and reliability are clear as well:
    - WTE recovers approximately 600 kWh of electricity per ton of waste, which is approximately **10 times the electric energy recoverable from a ton of landfilled waste**. Att. 3, p. 1714; *see also* Att. 4, p. B-29.
    - In addition, WTE is the **paradigm example of "distributed generation"** that serves nearby load without the need for new long-distance transmission lines.
    - WTE is also **base-load generation**, available 24/7 and unaffected by days that are cloudy or calm.
- It should also be noted that **GHG emissions from WTE are primarily of biogenic origin** (approximately two-thirds). Att. 3, p. 1716.
    - These emissions are already part of the natural carbon cycle because the biogenic carbon that comprises paper, food and other biomass in municipal waste is removed from the atmosphere as part of the plant growth-natural carbon cycle.

  - The remaining petrochemical-based material (approximately one-third) can also be considered renewable (it's generated year after year), but when relegated to landfilling rather than combustion with energy recovery, the result is the loss of a vast amount of valuable energy – **WTE recovers the energy equivalent of one barrel of oil from each ton of MSW**.

- Not surprisingly, The Nature Conservancy ranks WTE as one of the most environmentally protective alternative energy sources. Att. 8, p. 24; *see also* "*Ask the Conservationist; August 2011: Can Trash Solve Our Energy Problems?*" http://www.nature.org/ourscience/-sciencefeatures/ask-the-conservationist-august-2011.xml

WTE ENCOURAGES RECYCLING – Finally, WTE is also entirely compatible with recycling:

- **WTE communities outperform non-WTE communities in recycling, with recycling rates that are typically at least 5 percentage points above the national average** and in some cases lead the nation in recycling. Att. 9, pp. ii, 8.
- These points are confirmed by a June 2009 national survey that conservatively calculated (i.e., understated) the recycling rate for WTE communities. *Id.*, pp. ii, 6-11.[6]
- Although recycling rates are driven by state recycling policies that apply equally to WTE and non-WTE communities, **WTE communities' recycling rates are generally higher than non-WTE communities in the same state**. *Id.*, p. 11 and Figure 3.
- State laws and policies also discourage diversion of recyclable materials to combustion in a WTE facility:
  - For example, an Oregon county using WTE cannot "take any action that would hinder or discourage recycling activities in the county." Ore. Rev. Stat. § 459.153. That statute is focused on WTE-reliant Marion County, which **consistently achieves one of the highest recycling rates in the nation – more than 60.8%**.[7]

RECAP AND CONCLUSIONS

- ► WTE – a significant source of renewable energy that substantially reduces GHG emissions by (a) displacing electric power generation from fossil fuels, (b) avoiding methane emissions from landfill disposal of municipal waste, and (c) facilitating post-combustion recovery and reuse of ferrous and non-ferrous metals.
- ► Clean, baseload energy with very low emissions.
- ► Recovers 10 times the energy (electric power) from a ton of waste in comparison to landfill methane recovery-reuse.
- ► "Distributed" generation, i.e., energy is used where it is generated, which reduces the environmental impact and cost of transporting both waste and energy.
- ► WTE complements recycling programs rather than competing with recycling.
- ► But as is often the case with environmentally preferred alternatives, WTE can cost more (at least on a short-term and intermediate basis) – **Our communities accept the higher cost precisely because the result is better for the environment**.

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[1] *The State of Garbage in America*, http://www.jgpress.com/images/art/1010/bc101016_s.pdf (*BioCycle*, Oct. 2010).

[2] http://epp.eurostat.ec.europa.eu/portal/page/portal/waste/data/sectors/municipal_waste.

[3] The 43.2 million-ton figure noted in the text for reduced landfill CO_2e emissions due to increased WTE usage was calculated based on: (i) data provided in *The State of Garbage in America* (BioCycle, Oct. 2010), *supra* n.1 (Table 2, which shows U.S. landfill disposal of approximately 270 million tons in 2008); and (ii) EPA's factor (cited in the text above) of one ton of landfill CO_2e emissions avoided per ton of WTE-processed MSW. Increasing WTE usage in the U.S. to 23% (from the current 7%) would reduce landfill CO_2e emissions by the previously noted 43.2 million tons, and using EPA data for annual CO_2e emissions per passenger car (4.8 metric tons, or 5.29 tons), *see* http://www.epa.gov/cleanenergy/energy-resources/refs.html#vehicles, a 43.2 million-ton reduction in landfill emissions equals the annual CO_2 emissions of 8,170,000 passenger cars.

[4] *See* http://www.energyrecoverycouncil.org/userfiles/file/epaletter.pdf.

[5] *Municipal Solid Waste in the United States: 2007 Facts and Figures*, p. 11.

[6] The WTE communities' recycling rate omits several recyclables that the national rate includes, and the national rate is a composite that *includes* WTE communities – the more accurate comparison would *exclude* WTE communities in calculating the national rate.

[7] *See 2011 Oregon Material Recovery and Waste Generation Rates Report*, October 2012 (12-LQ-038), Table 1, http://www.deq.state.or.us/lq/pubs/docs/sw/2011MRWGRatesReportTable01.pdf.

September 2013

ENCLOSURE 4

SCIENTIFIC TRUTH ABOUT
WASTE-TO-ENERGY

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PREFACE

Our society's increasing focus on the interrelationship of energy and the environment, including in particular sustainable waste management, has prompted the need for a comprehensive review of generating energy from waste. While there is growing interest in a circular economy that facilitates productive reuse of municipal solid waste (MSW), there is also significant confusion and misinformation regarding sustainably managing MSW using thermal conversion – or "Waste-to-Energy" (WTE). But juxtaposed to that confusion and misinformation are the facts, which show that WTE plays a key role as part of an environmentally sound system that includes full protection of human health and where post-recycled MSW supplies the energy to serve residential, commercial and industrial needs.

That is the context for this study, which provides the most up-to-date information on WTE and the environment, and can serve as a comprehensive resource for policy makers and others interested in learning more about the quantifiable benefits of WTE. The study has been reviewed by the following experts who possess first-hand knowledge and experience with WTE and are recognized internationally for their research and other scientific and engineering contributions. Their review ensures that the information and data presented are accurate and up to date. Any opinions or interpretations are those of the author only.

Prof. Nickolas Themelis – Columbia University

Prof. Ashwani Gupta – University of Maryland

Prof. Frank Roethel – State University of New York, Stony Brook

Mr. Anthony Licata – ASME Fellow, Licata Energy & Environmental Consultants, Inc. (formerly of Babcock Engineering)

Institute of Energy and Resource Management (IERM)

Dr. Helmut Schnurer (Former Deputy Director General at the Ministry for Environment, Germany – 40+ years in Waste Management , German & EU Policies)

Dr. Michael Weltzin (Senior Scientific Advisor to German Green Party on Waste and Climate Policy – 20+ years in Waste Management and Climate)

Rene Moeller Rosendal (Danish Waste Solutions, ISWA Vice Chair Landfilling – 20+ years in Waste Management focus Landfilling)

Dr. Richard Honour (Executive Director The Precautionary Group, Specialist in Environmental Toxicology, Infectious Diseases and Cancer – 50+ years)

Philipp Schmidt-Pathmann, MBA, MIS (Founder and Executive Director, IERM – 20+ years in WTE and Waste Management US and Europe)

Cover Photo: Solid Waste Authority of Palm Beach County (FL) Renewable Energy Facility 2, the newest waste-to-energy facility built in the U.S. which started commercial operations in 2015. https://swa.org/Facilities/Facility/Details/Renewable-Energy-Facility-2-11

SUMMARY

The world has more municipal solid waste now than at any point in history. In the U.S. alone, we generate nearly 300 million tons a year, a number that rises each year as our population grows, according to the most recent federal data. This waste is managed in the U.S. in three ways: recycling and composting (34.7%), waste-to-energy (12.8%) and treatment and disposal, primarily by landfilling (52.5%)

Waste-to-energy is the better alternative to landfilling for managing MSW that is not recyclable, a reality explicitly recognized by the waste management hierarchy recommended by both the U.S. Environmental Protection Agency and the European Union. With 76 WTE facilities in the U.S. and 410 in Europe (and many more in operation and under construction or planned in Asia and elsewhere), WTE is a proven technology for heating, cooling, industrial processes and electric power production that displaces fossil fuels and at the same time has a significantly lower carbon (greenhouse gas) footprint compared to landfilling. WTE also has the added benefit of destroying contaminated materials that contain pathogens and viruses.

While there is great interest in increasing recycling and materials recovery, with many communities working toward laudable zero-waste goals, a number of factors limit our ability to significantly increase recycling, including: the economics of recycling have deteriorated due to reduced demand for recyclables, the cost of producing salable products from recyclable materials has increased due to a changing waste stream and more sophisticated and expensive processing requirements. As a consequence, landfill volumes and the methane they generate continue to increase.

As the reader will see, the pages that follow describe a very important opportunity for the United States, that is, the key role WTE can serve in a sustainable waste management future that is fully protective of human health and the environment.

In this report, readers will build a better understanding of the scientific realities of Waste-to-Energy as it relates to waste management, recycling, public health and the environment, including:

- Although landfills are the primary alternative to Waste-to-Energy, methane emitted by landfills is the second largest contributor to global climate change. New data show methane is even more damaging than previously thought.
- Every ton of waste processed in a WTE facility avoids a ton of CO_2 equivalent emissions, when the Greenhouse Gas savings from recycling recovered metals is included. Over 700,000 tons of metal are recovered and recycled annually in WTE facilities.
- U.S. counties and municipalities that use WTE consistently show an increased recycling rate.
- Independent studies show human health is not adversely affected by waste-to-energy. Further, WTE facilities in the U.S. and globally operate well within environmental standards. Data show their emissions are more than 70% below regulatory limits, except for NOx, which operates at 35 % below emissions limits.
- The overwhelming trend worldwide is the growth of WTE facilities to manage the increasing amount of waste while extracting energy and valuable materials for recycling.
- Evaluating WTE in isolation is misleading as it leaves out the net effect of the environmental and energy impacts of landfilling the waste often great distances away from the source of generation.
- Reduce, reuse, and recycle are generally recognized by the public; however, there is less awareness and knowledge of recovery and the supporting technology. Further, there is significant misunderstanding of the energy recovery process.
- There are 76 waste-to-energy facilities in the US that process nearly 94,000 tons of municipal solid waste per day, producing enough energy to power the equivalent of 2.3 million homes.
- WTE is a $10 billion industry that employs approximately 6,000 American workers and is growing worldwide and should be in the U.S.

TABLE OF CONTENTS

INTRODUCTION

Waste-to-Energy is a critical component of the accepted municipal waste management hierarchy and can be a significant tool to avoid landfilling waste after reduction, reuse and recycling. This report summarizes how WTE is a key part of a sustainable waste management solution and a responsible alternative when environmental and human health impacts are considered. Details are provided on the performance of WTE facilities, with a focus on the U.S., and the complementary relationship between recycling and WTE. Representative publications are presented and summarized with citations to allow interested readers to fully explore the extensive body of literature pertaining to performance and operation of WTE.

I. SUSTAINABLE WASTE MANAGEMENT HIERARCHY

The United States generated nearly 300 million tons of municipal solid waste in just one year, a figure that rises as the population grows, according to the latest figures from the U.S. Environmental Protection Agency. The EPA's accepted best practice to sustainably manage solid wastes is shown in Figure 1 developed by the US EPA (USEPA, 2019). This hierarchy has been established based on minimizing environmental impacts of waste management procedures and has been accepted by environmental and scientific organizations worldwide (e.g. International Solid Waste Association (https://www.iswa.org/), Solid Waste Association of North America (https://swana.org), and The United Kingdom Department of Environmental and Rural Affairs (DEFRA) (https://www.gov.uk). Importantly, this hierarchy is not new; it has been recognized for three decades since the Resource Conservation and Recovery Act (RCRA) first passed in 1976 and been adopted by over 30 states. The Waste Management Hierachy has been re-confirmed many times as the best way to manage MSW with the least environmental and human health impacts. As the European Commission embarks on its path to a more circular economy, it has re-affirmed the place that efficient energy recovery can play in an overall sustainable waste management strategy(European Commission, 2017).

Figure 1. demonstrates that once reduction, reuse, and recycling have been deployed, the remaining waste should be processed for energy recovery. The energy recovery from waste is consistent with the hierarchy and provides an opportunity for additional recovery of materials such as aluminum, iron, copper and other non-ferrous metal. Energy and material recovery is consistent with the National Research Council's conclusion that the current paradigm of waste generating processes must move to a future paradigm of an atom economy (e.g. all atoms from a waste stream are productively incorporated into a final product – either material or energy) that includes energy and material recovery from MSW (National Research Council, 2005). The hierarchy's least preferred option is labeled "treatment and disposal" which means landfilling. The hierarchy shown provides clear guidance that both material recovery via reuse, recycling and composting, followed by recovery of energy, should precede any waste being sent to landfills.

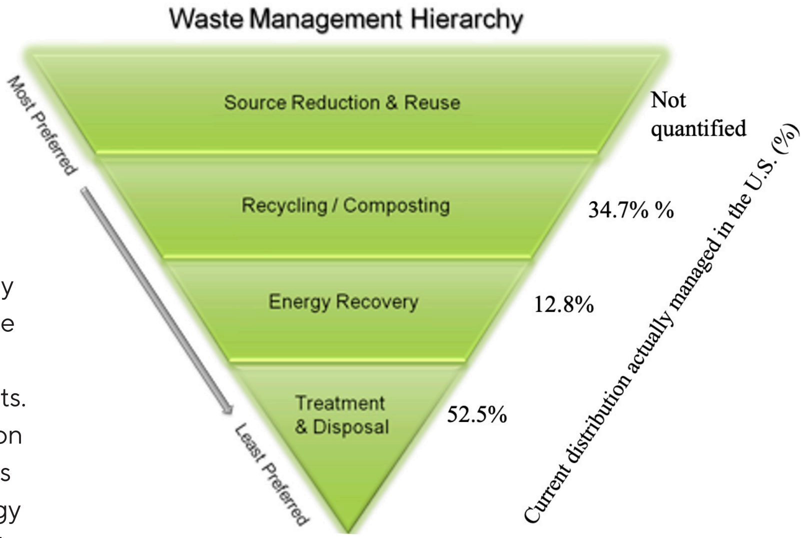


Figure 1. Sustainable Waste Management Hierarchy. (source USEPA)

Reduce, reuse and recycle are generally recognized by the public, however, there is less awareness and knowledge of recovery and the supporting technology. Furthermore, there is significant misunderstanding of the energy recovery process for MSW management. Several surveys have revealed that public awareness of WTE is low (Leung and Heacock, 2015), but once WTE's role in integrated waste management is explained the public develops a positive opinion. Specifically, research conducted by the Earth Engineering Center (EEC) at The City College of New York (CCNY) and results of other published surveys reveal public respondents preferred waste to energy over landfilling (Bremby, 2010; Casey Cullen, et al., 2013; Baxter et al., 2016). For example, a recent EEC|CCNY Capstone survey revealed that approximately 30% of NYC residents did not know where their trash went after they threw it away and when they were informed of waste to energy, approximately 88% preferred WTE processing for their trash rather than landfilling (Casey Cullen, et al., 2013). Since thermal conversion of wastes to energy employs complex, high-temperature facilities, that also destroy toxins and provide material for the construction industry, it is not surprising that it is the least understood among the waste management options.

> *There are 76 WTE facilities in the U.S. that process nearly 94,000 tons of MSW per day producing 2.5 GW of electricity and 2.7 GW of combined heat and power (www.erc.org). This equates to approximately 13% of all MSW generated in the U.S. and powers 2.3 million homes.*

Significant differences between thermal conversion technologies have developed over the years. One of the main differences is the amount of air, or oxygen, that is used during the conversion process and therefore the commensurate temperature that is achieved. These technologies span the range of air usage with pyrolysis operating without any air, gasification using near stoichiometric amounts of air, and combustion using excess air or a quantity of air greater than the stoichiometric requirement. The use of excess air has advantages that have resulted in combustion systems becoming the predominant thermal conversion technology.

WTE differs from combustors that are classified as incinerators because of the energy recovery component. In WTE facilities the heat generated by waste combustion is transferred to steam that flows through a turbine to generate electricity. In some installations there also is a direct sale of the steam to commercial customers for heating, cooling or other purposes.

Moreover, the design of a WTE facility allows for the recovery of metals and minerals for recycling purposes. WTE facilities differ from other waste combustion facilities that process only hazardous or medical wastes. Facilities that process hazardous waste or medical waste are true waste incinerators because they are designed to thermally destroy the incoming waste without provisions for energy or material recovery. WTE facilities and incinerators both use a high temperature combustion process followed by air pollution control (APC) systems, yet, only WTE captures the energy released from combustion to produce power and steam while recovering additional materials for recycling. On the other hand, energy released from hazardous and medical waste incinerators is not recovered and no additional material is recovered for recycling but goes directly to landfill.

Hempstead, NY WTE Facility located 29 miles from New York City

There are 76 WTE facilities in the U.S. that process nearly 94,000 tons of MSW per day producing 2.5 GW of electricity and 2.7 GW of combined heat and power (www.erc.org). This equates to approximately 13% of all MSW generated in the U.S. and is enough to power the equivalent of 2.3 million homes. There are 22 incinerators (http://www.ehso.com/tsdfincin.php) that process a negligible amount of medical and hazardous wastes according to the US EPA. Although internationally the terms WTE and incineration are often used synonymously, in the U.S. the US EPA refers to WTE as MSW Combustion.

The overwhelming trend worldwide is the growth of WTE facilities to manage the increasing amount of MSW while extracting energy and valuable materials for recycling. There is an enormous rate of growth in China and developing countries, while Europe, which is a very mature market, has 410 installations spanning 23 countries. Developing countries that strive to sustainably manage their waste are beginning to employ WTE. Addis Abba recently completed the commissioning of a WTE unit while Lithuania and Minsk are getting ready for construction. In the U.S. one new facility was built in Palm Beach County, FL in 2015 and there have been several expansions of existing plants such as in Lee County and Hillsborough County, FL.

There are several configurations that can be used in WTE facilities; however, the dominant design accepts unprocessed, as-received MSW from collection trucks or containers and combusts the MSW on specially designed moving grates. Depending on the heat recovery boiler design and design steam conditions, WTE facilities net electrical energy generation is in the range of 550-700 kilowatt hours (KWh) per ton of MSW combusted. Compared to landfilling, this process is an efficient use of the waste remaining after recycling efforts have been exhausted. WTE facilities are 6-11 times more effective at capturing the energy contained in MSW than landfilling (Kaplan, Decarolis and Thorneloe, 2009). When built near a use of heat energy, WTE facilities can be put together with a combined heat and power configuration, further increasing overall efficiency of the process. This is more common in Europe where WTE facilities tend to be in urban centers to provide steam for city heating and cooling along with power, but examples in the U.S. include WTE facilities built as an integral part of both industrial and municipal steam loops. In addition, there are possibilities of co-generation (heat and electricity). The Baltimore facility generates enough electricity to power nearly 40,000 homes while simultaneously providing steam to the downtown Baltimore district heating loop that serves 255 businesses.

To encourage efficiency, policies in Europe set a minimum threshold to be considered energy recovery. Typically, the net electrical efficiency of WTE facilities is in the range of 25%. Hence, for a 100 MW plant (corresponding to 32 t/h of waste at about 11 GJ/ton) roughly 25 MW of electricity can be sold to the grid (this is because the temperature of the heat exchangers needs to be limited to avoid excessive corrosion) and about 55 MW is rejected. Thus, if there is no demand for the steam generated a large amount of energy will not be beneficially reused. If there is heating demand in the vicinity of the WTE facility, such as residential heating or a similar industrial process, a large portion of that 55 MW would then be put to productive use. The facilities in the U.S., and abroad, operate as continuous, base-load units often located next to load centers with 92% or higher availability.

Typically, MSW contains about 20% non-combustible material on a dry basis that converts to an ash and is discharged at the exit of the combustor. There is a small portion, approximately 3%, that becomes fly ash. The fly ash and APC scrubber residue are captured in the baghouse or ESP particulate control section of the APC system. In the U.S. fly ash is often mixed with bottom ash making it less suitable for construction purposes. However, that practice is beginning to change. Globally considerable amounts of bottom ash are used productively in construction projects as aggregate in road bed and concrete, however, in the U.S. there is minimal use of bottom ash for construction and its beneficial use is mostly confined as an alternate daily cover in landfills or shipped to ash mono-fills. However, as the operations of WTE companies evolve, more bottom ash is beginning to be used for construction aggregate (Klinghoffer and Castaldi, 2013; Leckner, 2015; Reddy, 2016; Makarichi, Jutidamrongphan and Techato, 2018).

> *In the sustainable waste management hierarchy, the deployment of WTE as part of a holistic solution will lead to a zero-waste scenario.*

In the sustainable waste management hierarchy, the deployment of WTE as part of a holistic solution will lead to a zero-waste scenario; especially when all the bottom ash is used in building or construction projects. That concept has been recognized by the U.S. Department of Energy's (US DOE) Advanced Research Projects Agency stating that MSW can be "an abundant and sustainable source of energy and valuable elements" (ARPA-E, 2020). WTE ash utilization and energy generation strategy are far more efficient than landfill gas to energy (LFGTE) projects. LFGTE extracts about 10% of the energy in the MSW and does not enable any material recovery. Currently, a heavy-metal containing filter cake, from the baghouse, is produced, which is removed from the system separately. They are relatively small amounts and should not be reused.

Dublin Waste-to-Energy Facility – www.dublinwastetoenergy.ie

> *"Every ton of waste processed at a WTE facility avoids a ton of $C0_2$ equivalent emissions."*
>
> *– Brunner and Rechberger*

II. GREENHOUSE GAS (GHG) SAVINGS FROM WTE

There are numerous studies that have quantified the reduction in GHG emissions when WTE is used to manage MSW. A large body of literature employs life cycle assessments (LCA) to calculate the potential GHG savings when using WTE versus other MSW management options. This is also widely recognized by the scientific and engineering communities as well as numerous state legislatures and non-profit organizations. Some examples include the Intergovernmental Panel on Climate Change ("IPCC"), the World Economic Forum (Liebreich et al., 2009), and the Center for American Progress as well as the various states, including Pennsylvania (Pennsylvania Environmental Protection Department, 2019), New York (Solid Waste Advisory Group, 2010), Maryland, Maine (Maine Department of Environmental Protection; Joint Standing Committee on Natural Resources of the Maine Legislature, 2004) and Florida (Florida Climate Action Team, 2008). Typical MSW WTE stack emissions routinely meet US EPA's Maximum Achievable Control Technology (MACT) standards and contain, on average, 63% biogenic CO_2, derived from non-fossil carbon or biomass that is already part of the biosphere. Moreover, if the GHG savings from recycling the 50 pounds of metal recovered from every ton of MSW processed in a WTE facility is included, it is evident that every ton of MSW processed in a WTE facility avoids a ton of CO_2 equivalent emissions (Brunner and Rechberger, 2015). Importantly, a recent United Nations Environment Programme (UNEP) report "District Energy in Cities: Unlocking the Potential of Energy Efficiency and Renewable Energy" states that Paris currently meets 50% of its heating needs using three WTE plants that avoid 800,000 tons of CO_2 emissions each year. These savings result because the low-carbon electricity produced from WTE offsets electricity production from facilities that rely on fossil fuels (UNEP, 2015).

It is critical that the assumptions and boundary conditions used for the LCA analyses are well understood and representative of real-life parameters. An excellent recent review of 250 WTE case-study scenarios across 136 journal articles identifies shortcomings and provides recommendations for best LCA practices for WTE (Astrup et al., 2015). Comparing WTE and landfill emissions requires use of a life cycle methodology that considers total emissions over time for a ton of MSW either combusted via WTE or buried in a landfill. The US EPA, in collaboration with US DOE, developed the MSW Decision Support Tool (DST) for use by communities in developing more sustainable solid waste management plans to optimize resource and energy recovery. The US EPA conducted a study using the MSW DST to compare life-cycle emissions from either burning or burying MSW. The total life cycle inventory (LCI) emissions from landfills are the summation of the emissions resulting from (1) the site preparation, operation, and post closure operation of a landfill, (2) the decay of the waste under anaerobic conditions, (3) the equipment utilized during landfill operations and landfill gas management operations, (4) the production of diesel required to operate the vehicles at the site, and (5) the treatment of leachate. The production of LFG was calculated using a first-order decay equation for a time horizon of 100 years and the empirical methane yield from each individual waste component. The total LCI emissions from WTE are the summation of the emissions associated with (1) the combustion of waste, i.e., the stack gas (accounting for air pollution controls), (2) the production and use of limestone in the air pollution control technologies (i.e., scrubbers), and (3) the disposal of ash in a landfill. The results indicated that the greenhouse gas emissions for WTE range from 0.4 to 1.5 $MTCO_{2e}$/MWh, whereas the most aggressive LFGTE scenario results in 2.3 $MTCO_{2e}$/MWh yet could be has high as 5.5 $MTCO_{2e}$/MWh.

A United Nations report highlights how Paris avoids 800,000 tons of CO_2 with its three WTE facilities.

The landfill emission factors include the decay of MSW over 100 years, whereas emissions from WTE and conventional electricity-generating technologies are instantaneous. The operation and decomposition of waste in landfills continue even beyond the monitoring phases for an indefinite period. Reliably quantifying the landfill gas collection efficiency is difficult due to the ever-changing nature of landfills, number of decades that emissions are generated, and changes over time in landfill design and operation including waste quantity and composition. Landfills are an area source, which makes emissions more difficult to monitor. In a recent release of updated emission factors for landfill gas emissions, data were available for less than 5% of active municipal landfills. Across the United States, there are major differences in how landfills are designed and operated, which further complicates the development of reliable emission factors. Therefore, a range of alternative scenarios are evaluated with plausible yet optimistic assumptions for LFG control. For WTE facilities, there is less variability in the design and operation. In addition, the US EPA has data for all the operating WTE facilities as a result of CAA requirements for annual stack testing of pollutants of concern, including dioxin/furan, Cd, Pb, Hg, PM, and HCl. In addition, data are available for SO_2, NO_x, and CO from continuous emissions monitoring. As a result, the quality and availability of data for WTE versus LFGTE yields a greater degree of certainty for estimating emission factors for WTE facilities.

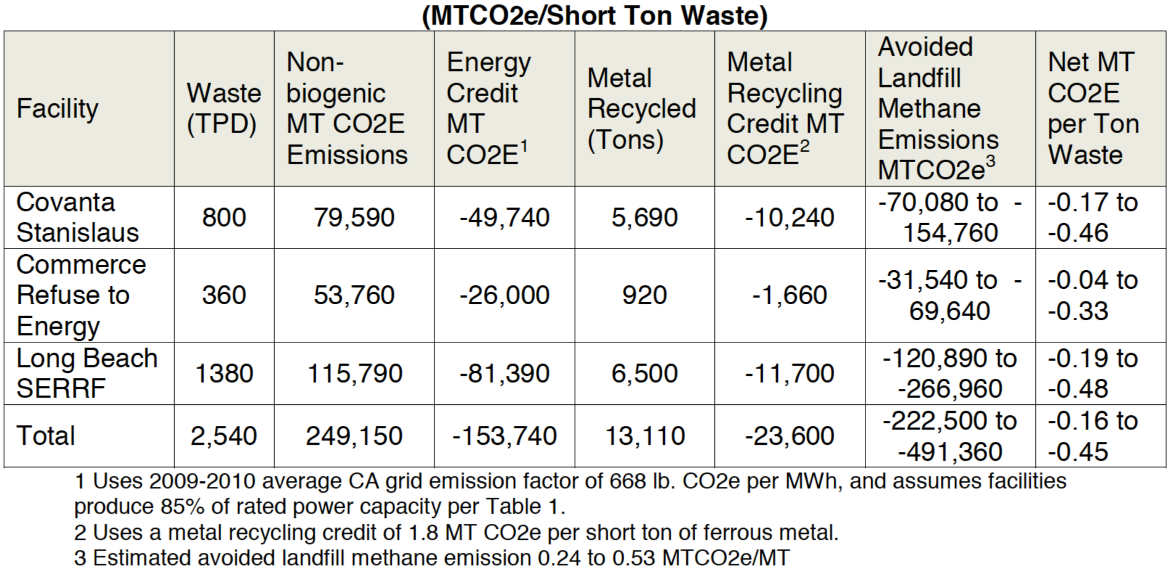
One notable difference between LFGTE and WTE is that the latter can produce an order of magnitude more electricity from the same mass of waste. In addition, there are significant differences in emissions on a mass per unit energy basis from LFGTE and WTE. While the production of methane in landfills is the result of the anaerobic breakdown of biogenic materials, a significant fraction of the energy derived from WTE results from combusting fossil-fuel-derived materials, such as plastics. Countering this effect, however, is significant methane leakage ranging from landfills with CAA requirements mandating air pollution control in the buried waste, up to 5 years from waste burial. Food waste decomposes within 3 to 5 years of burial resulting in the methane being emitted prior to controls in place. In addition, WTE facilities are required to have performance testing and the data is accessible to US EPA and the public. Landfills require use of a model (i.e., LandGEM) that relies on a 1st order decomposition rate equation that has been found by US EPA to vary by several orders of magnitude. Emissions from waste burial continue for multiple decades requiring future generations to bear the cost of controlling emissions from landfills. Landfills are typically hundreds of acres, while WTE is a much smaller footprint easily located in major population areas as is done in Europe. The public has access to emissions data from WTE through 24/7 reporting using continuous emission monitoring. There is tremendous uncertainty in quantifying landfill emissions and recent NASA data using aircraft suggest the current US EPA estimates for landfill methane may be understated by a factor of two (Duren et al., 2019).

Increased Recycling: WTE plants currently recover nearly 700,000 tons of ferrous metal for recycling annually, which avoids CO_2 emissions and saves energy compared to the mining of virgin materials for manufacturing new metals.

Validation of the LCA studies is very important (Kaplan, DeCarolis and Barlaz, 2012). A past issue, which has since been corrected, with the US EPA's MSW-Decision Support Tool used a carbon storage factor that assumed more biogenic carbon is stored than existed in the waste which is usually 0.27-0.30 grams of carbon per gram of MSW, and some studies arrived at a carbon storage factor of 0.417 grams of carbon per gram of MSW (Morris, 2010) which would only account for old newsprint and leaves (Barlaz, 2008). Therefore, the results of LCA studies should be used to complement detailed analyses based on actual measurements and data for a particular site.

One analysis that is often done is the GHG footprint of a landfill/landfill gas to energy (LFGTE) facility compared to WTE. However, studies by the US EPA determined that WTE can produce an order of magnitude more electricity from the same mass of waste resulting in greater GHG reductions per kWh of electricity compared to LFGTE. Thus the GHG savings accrues from electricity produced from WTE that offsets electricity production from facilities that rely on fossil fuels.

Again, considerable attention needs to be given to the data and assumptions to obtain a relevant result for the case being developed. For example, methane emission rates from landfills vary by nearly an order of magnitude because experimentally determined rates ranged from 35 to 167 m^3 CH_4/Mg MSW and values used in modeling span from 20 to 223 m^3



(MTCO2e/Short Ton Waste)

Facility	Waste (TPD)	Non-biogenic MT CO2E Emissions	Energy Credit MT CO2E[1]	Metal Recycled (Tons)	Metal Recycling Credit MT CO2E[2]	Avoided Landfill Methane Emissions MTCO2e[3]	Net MT CO2E per Ton Waste
Covanta Stanislaus	800	79,590	-49,740	5,690	-10,240	-70,080 to -154,760	-0.17 to -0.46
Commerce Refuse to Energy	360	53,760	-26,000	920	-1,660	-31,540 to -69,640	-0.04 to -0.33
Long Beach SERRF	1380	115,790	-81,390	6,500	-11,700	-120,890 to -266,960	-0.19 to -0.48
Total	2,540	249,150	-153,740	13,110	-23,600	-222,500 to -491,360	-0.16 to -0.45

1 Uses 2009-2010 average CA grid emission factor of 668 lb. CO2e per MWh, and assumes facilities produce 85% of rated power capacity per Table 1.
2 Uses a metal recycling credit of 1.8 MT CO2e per short ton of ferrous metal.
3 Estimated avoided landfill methane emission 0.24 to 0.53 MTCO2e/MT

Figure 2. CARB's analysis showing specific WTE facilities' ability to reduce GHG emissions(California Air Resources Board, 2013) N.B. Commerce recently closed

The amount of CO_2 savings from the CARB analysis ranges from 122,080 to 343,350 metric tons of CO_2 per ton of MSW processed in one year.

CH_4/Mg MSW (Krause et al., 2016). In addition, it is known that each waste component's rate of decay is also a result of the site-specific environment, which creates more uncertainty when modeling (Krause, 2018). Moreover, the actual use of heat from LFGTE and WTE operations needs to be more accurately identified because relative GHG impact (WTE versus landfills/LFGTE) cannot be measured without knowing the energy supply that will be offset. Thus, evaluating WTE in isolation is very misleading as it leaves out the net effect of the environmental and energy impacts of landfilling the waste often great distances away from the source of generation.

Using WTE in conjunction with source separation recycling/composting systems can achieve virtually zero waste-to-landfills. In addition, as much as 90 percent by weight of the mass sent to a WTE facility can be reduced if the minerals in the ash are recovered for road construction. Moreover, WTE facilities also allow post-combustion (as well as pre-combustion) recovery of metals for recycling. WTE plants currently recover nearly 700,000 tons of ferrous metal for recycling annually, which avoids CO_2 emissions and saves energy compared to the mining of virgin materials for manufacturing new metals.

One under-appreciated aspect of the residual ash produced by WTE is the large amount of concentrated metals that can be recovered and reused. These metals range from common iron, aluminum and copper and are in large amounts. For example, from a 600 ton per day MSW WTE facility, annual ash processing has been shown to extract approximately 6,300 tons of iron, 3,400 tons of aluminum and 440 tons of copper. Multiply this by the 76 plants operating in the U.S. and it is obvious there is a significant driver for the recycling industry. Furthermore, the ash contains a significant amount of rare and critical materials such as silver (0.98 tons/year), rubidium (1.5 tons/year), yttrium (1.4 tons/year), neodymium (1.3 tons/year), and gallium (0.40 tons/year) (Morf et al., 2013) that could potentially be extracted for beneficial use. But the importance of this point is most clearly demonstrated by the vast quantities of valuable metals entombed year-in and year-out due to landfilling of MSW(ARPA-E, 2020).

Mentioned above, for more than 30 years, more than half of the states in the U.S. recognize that

WTE reduces GHG emissions and many have incorporated that important factor into their climate plans (USEPA, 2015). In fact, Florida counties have benefitted by selling carbon credits into the voluntary market for several years. Pennsylvania's 2009 Climate Action Plan calls for the expansion of WTE to help reduce GHG emissions by reducing landfilling and increasing electricity generation. Specifically, Pennsylvania recommends increasing the state's WTE capacity by 40% by 2030 at existing facilities with a savings of $34/ton of GHG reduced and the 2019 plan affirms that effort (Pennsylvania Environmental Protection Department, 2019). Maryland considers WTE as a Tier 1 renewable energy source and it has been reported that without the WTE facilities it will be more difficult for it to achieve its Tier 1 goals (Peterson et al., 2019).

WTE Incorporated in State Plans to Fight Climate Change

[PA] Environmental regulators recommend increasing WTE by 40% by 2030
[MD] Recognized as a Tier 1 renewable energy source
[ME] Cost savings of 40% less per ton for carbon reduction

Maine similarly relies on WTE as part of its GHG reduction effort and estimates that it will cost ~40% less per ton of carbon compared to reductions through its solar water heater program. Electric generating plants fired by MSW are included as eligible renewable sources under Maine's Renewable Resource Portfolio requirement (Maine Department of Environmental Protection; Joint Standing Committee on Natural Resources of the Maine Legislature, 2004). St. Paul, MN displaces 275,000 tons of coal annually using processed yard waste as its fuel for district heating at its downtown plant (UNEP, 2015). This is similar for the WTE facilities in Baltimore, Indianapolis, and Minneapolis that co-generate steam and sell to downtown district energy systems in addition to producing power for sale to the grid. Finally, one particularly noteworthy example is the data shown in Figure 2 from California's Air Resource Board (CARB), which recognizes that the use of WTE reduces GHG emissions ranging between 0.16 and 0.45 MT CO_{2e} per ton of waste disposed.

The data in Figure 2 (taken from CARB's report) is from California and is particularly significant because of the special attention and often leading position California has taken with respect to environmental sustainability. The regulatory environment currently discourages WTE and in 2018, the Commerce City facility closed. Therefore, CA has lost some of its GHG reduction capacity as recognized by CARB. At the same time, recycling rates have decreased dramatically in the state and landfilling has increased.

WTE's climate benefits are even more striking considering methane's role as a short-lived climate pollutant ("SLCP"). New data show that the methane emitted by landfills and other sources is even more damaging than previously thought. Methane is the second largest contributor to global climate change (Stocker et al., 2014). Methane has a much larger climate impact than previously reported and its atmospheric concentrations continue to rise (World Meteorological Organization, 2013). According to the IPCC's 5th Assessment Report, methane is 34 times stronger than CO_2 over 100 years when all its effects in the atmosphere are included and 84 times more potent over 20 years (Myhre, Shindell and Pongratz, 2014).

III. HUMAN HEALTH IS NOT ADVERSELY IMPACTED BY WASTE TO ENERGY

The longstanding and well-documented scientific consensus is that human health is not adversely impacted by WTE. A National Research Council report in 2000 stated that pollutants such as particulate matter, lead, mercury, and dioxins and furans from well-run WTE facilities are expected to contribute little to environmental concentrations or to health risks (National Research council, 2000). The report called for more systematic studies to be done and a 2007 update states that epidemiological studies suggest there is no association between human health effects and the operation of WTE facilities (Chrostowski, 2007). A 2019 review stated that assessments of the impacts of WTE should consider direct pollutant emissions as well as the potential benefits of different waste management strategies on the community, suggesting that the health benefits of modern, properly managed WTE facilities may outweigh the health risks (Morgan et al., 2019). This section highlights several peer-reviewed scientific studies that present results showing WTE facilities do not adversely impact human health.

An extensive 7-year (2003-10) WTE study in Great Britain focused on impacts during pregnancy and infancy. The study modeled ground-level PM_{10} from WTE emissions within 4.5 miles of each facility and found that there was no excess risk for people living near WTE facilities (Ghosh et al., 2019). The authors specifically state:

"We found no evidence that exposure to PM_{10} *from, or living near to, an [WTE] operating to current EU standards was associated with harm for any of the outcomes investigated. Results should be generalisable to other MWIs [i.e., WTE facilities] operating to similar standards."*

US and International reports show human health effects cannot be directly connected to properly operating WTE facilities.

A second study by the same research group for the period 1996-2012 used Interrupted Time Series (ITS) methodology and found no evidence that WTE caused an increase in infant mortality when compared to control areas (Freni-Sterrantino et al., 2019). A 2011 study aimed at trying to quantify the attributable burden of disease from four (4) WTE facilities near Seoul used a combination of air modeling and the fraction associated with the emissions. That study estimated that over a projected 30-year operation approximately 446 ± 59% deaths may occur from the four (4) facilities combined and could be as low as 126 ± 59%. However, the calculations were completed under the assumption that the emissions from the WTE facilities were equal to the regulatory limit values. Yet the actual emissions produced by the four (4) WTE facilities were shown to be, on average, about one order of magnitude lower and the study did not account for residual risk factors (Kim, Kim and Lee, 2011). Therefore, the numbers are based on permitted levels yet actual emissions are significantly lower and residual risk was not incorporated, thus estimated deaths will be much lower than reported in that study.

Although estimations may provide some guidance when considering WTE, there is no substitute for site-specific analyses given the large variability in environmental conditions such as micro-climates, elevation, prevailing winds, existing industry, etc. Those variations must be accurately incorporated into targeted, precise analyses focused on the site chosen for a WTE facility. Moreover, consideration should be given to proximity of waste generation, transfer and use of steam for heating and cooling. Several recent studies for specific locales are highlighted here to provide context on the outcomes of health risk assessments related to WTE operation.

An assessment was done in 2004 for the WTE facility located in Montgomery County, Maryland near the town of Dickerson using health risk studies and ambient monitoring programs before and after the facility became operational. The study was comprehensive for air and non-air media (crops, farm pond surface water and fish tissue, and cow's milk) testing for several emissions including polychlorinated dioxins and furans and selected toxic metals (arsenic, beryllium, cadmium, chromium, lead, mercury, and nickel). The areas tested ranged from Beallsville, which was about 2.5 miles away to Burtonsville which was 25 miles away from the facility. The results of the testing after the facility was operational demonstrated no measurable difference compared to pre-operational ambient levels and no expectation of non-carcinogenic health effects as a result of facility emissions (Rao et al., 2004). The specific result of the health risk assessment performed found a 1.0×10^{-6} (1/1,000,000) for occurrence of potential carcinogenic health effects, which is 99% below the US EPA's upper limit of acceptable risk.

Recently, a new WTE facility was constructed in Durham, Canada. The facility currently operates at 140,000 tonnes per year and can be expanded to 400,000 tonnes per year. Two peer-reviewed articles were produced that focused on the risk to human health and found the facility is unlikely to pose undue risk at approved operating capacity (Ollson, Aslund, et al., 2014; Ollson, Knopper, et al., 2014). A similar finding was obtained for WTE facilities in Spokane WA and Lee County FL. Specifically, the probability of an individual contracting cancer from exposure to emissions through all exposure pathways ranged from 0.02 to 4 in 1 million. To provide context for that result, the typical background rate of cancer in the United States is 1 in 3. Importantly the findings were based on actual facility emissions and included exposure via multiple pathways (Chrostowski, 2007).

A 2017 study assessed potential associations between Baltimore's rate of asthma-related hospitalizations and economic and ambient air quality indicators. The study found "a very strong spatial correlation between asthma hospitalization and emergency room visits in Baltimore's zip codes and demographic measures of poverty, particularly median household income". While the study did find a potential association between some measures of local air pollution and asthma-related hospitalizations, the associations were more limited and related to air toxics, primarily from roadway vehicles. The researchers did not find any significant association with zip codes that contained the highest emissions of criteria pollutants from stationary facilities, including Baltimore, and found instead that air pollution from roadway vehicles was disproportionately effecting asthma rates in some areas of the City. (Kelly and Burkhart, 2017).

Another more recent study, using the most updated air dispersion model approved by the US EPA, specifically focused on possible connections between air quality impacts of NO_2, SO_2 and $PM_{2.5}$ emissions from the WTE facility and asthma rates. The study concluded there were no statistically significant associations between annual age-adjusted emergency room or hospital discharge rates for asthma in relation to annual average NO_2, SO_2 and $PM_{2.5}$ air concentrations due to emissions from the WTE facility. The study did, however, identify consistent statistically significant associations between discharge rates for asthma and median family income for the three years of available data and instances where discharge rates were also significantly associated with other socio-demographic parameters, such homeownership rate and housing vacancy rate. (Foster and Hoffman 2019).

The specific findings discussed above are consistent with several other international reports that show human health effects cannot be directly connected to properly operating WTE facilities. For example, a review of 21 peer-reviewed articles prepared for Metro Vancouver concluded that a modern WTE facility would not pose unacceptable health risks to residents (Intrinsik Environmental Sciences, 2014). Similarly, biomonitoring studies also showed no potential risks to humans or crops in the vicinity of three (3) WTE facilities in The Netherlands (Van Dijk, van Doorn and van Alfen, 2015) and no correlation to dioxin levels in blood for residents near a Portugal WTE facility (Reis et al., 2007). A similar conclusion related to heavy metals was obtained for a WTE facility built in 2005 in Bilbao, Spain. The study analyzed blood and urine samples over a two-year period from residents living from 2 to 20 km from the facility and did not find increased levels of heavy metals for the residents that lived near the plant (Zubero et al., 2010). A study done specific to a WTE facility in Italy found the excess risk of lung cancer for people living or working nearby the plant is below the WHO target (1×10^{-5}) (Scungio et al., 2016). Finally, the Ministry of Public Health in England determined that it is not able to connect any negative health impacts associated with well-regulated WTE facilities (Freni-Sterrantino et al., 2019; Parkes et al., 2020).

IV. PATHOGEN, PHARMACEUTICAL AND PROBLEMATIC CHEMICAL DESTRUCTION

WTE facilities are gaining attention related to the assured destruction of pathogens, waste pharmaceuticals and other problematic chemicals. Since pathogens and pharmaceuticals cannot sustain elevated temperatures because they are not capable of withstanding temperatures much above the biological regime, they are destroyed in the combustion environment of a WTE facility. The only similarity between incineration and WTE is that they both combust the waste with air and strive to achieve a well-established performance metric comprised of temperature, time, and turbulence, typically referred to as “the 3 T’s of combustion”. This metric has been demonstrated to be effective in establishing robust combustion performance covering a large range of materials. That is because MSW may contain pathogens or pharmaceuticals, and WTE systems are designed for the complete destruction of any living organisms and typically operate with a combustion gas temperature of greater than 850 °C and a residence time of greater than 2 seconds with a significant amount of turbulence (i.e., mixing) of the combustion gases and incoming air. The final off-gas is treated in an air pollution control system before being vented to the atmosphere.

Given these design features, scientists and engineers experienced in thermal conversion processes recognize that well-designed and well-operated WTE facilities will result in destruction and removal of viruses, enteric bacteria, fungi, human and animal parasites at an efficiency between 99.99 to 99.9999% (Ware, 1980). Several other studies have been done to assess the efficacy of WTE facilities to properly treat materials that could contain pathogens. This includes a US EPA study of Bacillus anthracis surrogates spiked on building materials (Wood et al., 2008), and another study on the use of incineration for destruction of Ebola (Barbeito, Taylor and Seiders, 1968). It is recognized that a sustainable waste management system should include disease vector and problematic chemical destruction, which is effectively done by WTE (Brunner and Rechberger, 2015). Finally, the recent attention given to halogenated flame retardants has prompted one workshop conducted by the Green Science Policy Institute to focus on best methods to keep those problematic chemicals out of the environment. The workshop identified WTE as a viable method based on an exhaustive analysis of all possible methods (Lucas et al., 2017).

V. UPDATED PRIORITY POLLUTANT EMISSIONS DATA FOR WTE FACILITIES

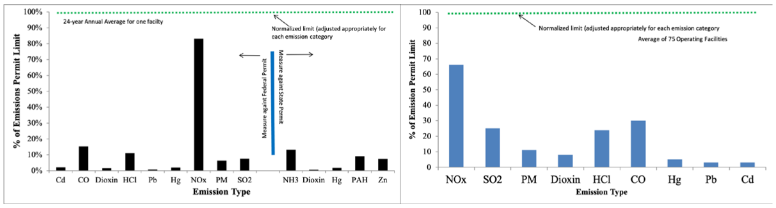


Figure 3. Emissions compared to federal and state limits. Left; results of an average of 70 operating facilities in the U.S. Right; Average stack emissions for 2019 and 25 years of operation for one facility

A review of the data on the current performance of WTE facilities shows emissions are far below regulated limits. The published literature on emissions data from WTE facilities needs to be periodically reviewed due to new findings and continual improvements resulting in frequent updates to the data. There are two reasons for this, the first is that MACT (Maximum Achievable Control Technology) standards are subject to a 5-year revision cycle by the US EPA and the second is that WTE facilities are constantly under public scrutiny. As a result, WTE facilities emissions are widely studied and well documented in the public domain and regulatory information portals.

> *The current performance of WTE facilities in the U.S., and globally, shows their emissions are more than 70% below MACT standards, except for NOx, which operates at approximately 35% below emission standards.*

The current performance of WTE facilities in the U.S., and globally, shows their emissions are more than 70% below MACT standards, except for NO_x which operates at approximately 35% below emission standards. Figure 3 shows the 2018 annual results from 70 facilities operating around the U.S.(Castaldi, 2020) and the 2019 stack test results compared to the 25-year performance for the facility in Onondaga County, New York (Onondaga County Resource Recovery Agency, 2020). The data shows that in all categories, the actual emissions are far below both federal and state limits.

The performance of the WTE fleet in the U.S. is like the performance of the best WTE facilities worldwide (Lu et al., 2017). In 2016, the latest fully compiled data, there a total of 1,618 plants worldwide with the majority in Europe (512) and China (166) (Scarlat, Fahl and Dallemand, 2019).

A significant number of studies have been done to isolate WTE emissions from other energy production facilities and transportation activities. However, studies of WTE emissions compared to transportation activities are normally done as case studies and therefore difficult to create broad averages or comparisons between facilities. Case studies are valuable because they account for local environmental conditions,

traffic patterns and temporal variations, must be as accurate as possible to obtain a robust and useful result. Consequently, it is difficult to find publications that provide broad averages like the above comparisons. Moreover, most of these investigations are done for European WTE facilities because they are in proximity to dense urban centers, precisely where the largest volumes of trash are produced.

One multi-year, multi-season study for Bolzano, Italy examined the sources of atmospheric pollutants using 6 sample collection stations to measure NO_x, ultra-fine particulate matter (10-300nm), PCDD/F and PAHs as well as to account for wind direction and elevation (Bolzano has a 400 TPD WTE facility) located near the city center. The temporal trends for ambient concentration variations in the local environment of particulate matter, PCDD/F, PAH and NO_x were exactly correlated with peaks related to traffic activities (Ragazzi et al., 2013) and the contribution from this WTE facility was demonstrated to be well below any regulatory threshold, thus negligible.

The Bolzono, Italy study isn't unique; additional measurement campaigns for other locations obtained similar results. A recent review of 70 published studies concluded that a WTE facility's contribution to the overall daily air pollutant dose to the affected urban populations was negligible. Explicitly, the study revealed the annual median background values were equal to 19,000 part cm^{-3},(i.e. 19,000 pollutant molecules per cubic centimeter of air volume) while the ultrafine particle concentrations at the stack of the WTE facilities were 5,500 part cm^{-3}. In other words, they were lower than the background concentration values (Buonanno and Morawska, 2015) and lower than measured downstream of a major highway (Buonanno et al., 2010). Another extensive review article that critically evaluated numerous publications reporting on 11 non-vehicle emission sources found a similar WTE facility average emission value of 1,300 part cm^{-3} for ultra-fine particulates. That emission amount is like domestic biomass burning (2,000 part cm^{-3}) and slightly higher than the ambient background found in Barcelona, Spain (600 part cm^{-3}) yet lower than restaurant/residential cooking (> 18,000 part cm^{-3}) (Kumar et al., 2013).

The primary sources of dioxin emissions come from high temperature processes (i.e., combustion, gasification, smelting, etc.) and dioxins can be generated via chemical manufacturing and microbial biotransformation of chlorinated compounds (Medicine, 2003). Due to the potency of these chemical species, there is valid concern to reduce their release to as low as practically possible. The investigations into the formation, removal, fate in the environment, health impacts and mitigation strategies have provided the scientific community with considerable understanding of dioxins and has led nearly every industry to implement strategies to prevent their release into the environment. Specifically related to the WTE industry, exhaustive efforts have resulted in a reduction of more than 99.5% from 1985 to 2012 (Vehlow, 2012) leading to the recognition that since 2005 WTE has not been a significant contributor of emissions of dioxins, dust or heavy metals (German Federal Ministry for the Environment, 2005). An inventory of dioxin emission sources in the U.S. quantitatively showed that the emissions contribution from all WTE facilities (i.e., compared to controlled industrial dioxin emissions) is 0.54% or 3.4 g TEQ (Dwyer and Themelis, 2015) and is consistent with other facilities worldwide (Tsai, 2010; Nzihou et al., 2012; Lu et al., 2017; Bourtsalas et al., 2019). To put these values into context, atmospheric concentration of dioxins after a fireworks display has been measured for an hour at 0.064 TEQ ng m^{-3} (Dyke, Coleman and James, 1997) to $0.061x10^{-3}$ TEQ ng m^{-3} (Schmid et al., 2014); for comparison, the average hourly dioxin emissions from a WTE facility are 0.030 TEQ ng m^{-3} (Dwyer and Themelis, 2015).

Mercury (Hg) emissions from WTE facilities is often cited as a concern. It is helpful that the use of mercury in the United States decreased significantly over the past 40 years and is continually being reduced. Many states and other government agencies have developed very successful programs for preventing disposal of mercury containing items in the MSW. The main sources of mercury in MSW were from batteries (mercury-zinc and alkaline) and fluorescent lamps. What mercury remains is captured in the WTE emission control systems which use activate carbon for this reduction scheme. For 40 years the annual Hg air emissions nationwide decreased from 246 tons per year to 52 tons per year with coal-burning power plants accounting for 44% in 2014 (USEPA, 2014). During a similar timeframe, WTE facilities reduced their mercury emissions by more than 96 percent, representing just 0.8% of man-made sources in 2014 (Bourtsalas and Themelis, 2019).

The different forms of Hg emissions require an understanding of possible deposition and environmental exposure routes. It was found that Hg levels in the blood and urine samples of residents near a Spanish WTE facility were not elevated compared to those 20 km away (Zubero et al., 2010). Similarly, an indirect study that focused on trace metals (e.g. Cd, Pb, Zn, etc), as well as several rare earth elements, did not show elevated concentrations in urban forests near WTE facilities. The cities chosen were Hartford, CT, Poughkeepsie, NY, and Springfield, MA (each has had a WTE facility operating in the immediate vicinity since 1989 (Richardson, 2020). Finally, some of the Hg remains in the WTE ash, which is disposed in designated monofills, used as alternate daily cover

Baltimore waste-to-energy facility

in MSW landfills and may be used as an additive in construction cement. If used as a raw ingredient during cement production, the ash amount should be limited to about 10% because higher amounts resulted in an uneven product (Clavier et al., 2020). Therefore, a portion of the Hg entering the WTE facility is captured as a solid which reduces its release into the environment.

Several WTE facilities post their emissions performance on-line and the US EPA maintains an emissions and generation resource integrated database (eGRID) that puts a focus on net electrical generation. (www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid) that can be easily accessed to obtain exact emissions from specific facilities, including:

- **Massachusetts DEP:** https://www.mass.gov/municipal-waste-combustor-emissions-reports
- **Onondaga County Resource Recovery Agency:** https://ocrra.org/about-us/information/reports-and-policies/#wtetesting
- **Durham-York Energy Centre:** https://www.durhamyorkwaste.ca/EmissionsData/EmissionsData.aspx
- **Montgomery County Resource Recovery Facility:** https://www.montgomerycountymd.gov/sws/facilities/rrf/cem.html

VI. ENVIRONMENTAL JUSTICE VALUES AND PROCEDURES

The US EPA defines environmental justice as follows: "Environmental justice is the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies." Best management practices have been established by an assembly of agencies; The Renewable Energy Action Team (REAT), California Energy Commission, California Department of Fish and Game, U.S. Bureau of Land Management, and U.S. Fish and Wildlife Service for renewable energy projects. The guidance, which is voluntary, identifies WTE and includes the following (Anderson et al., 2010):

1. Interlock the waste charging system with the temperature monitoring and control system to prevent waste additions if the operating temperature falls below the required limits.
2. Implement maintenance and other procedures to minimize planned and unplanned shutdowns.
3. Avoid operating conditions in excess of those that are required for efficient destruction of the waste.
4. Use a boiler to convert the fluegas energy for the production of steam/heat and/or electricity.
5. Use flue gas treatment systems for controlling acid gases, particulate matter, and other air pollutants.
6. Consider the application of WTE or anaerobic digestion technologies to help offset emissions associated with fossil fuel-based power generation.
7. Control dioxins and furans by extensive segregation to ensure complete plastics and other chlorinated compound removal.
8. For high performance dioxin removal, use an activated carbon packed column.

Many of these practices are implemented at currently operating facilities.

It is important to recognize that many facilities were built decades ago and the environment near the site may be very different today. Therefore, to fully understand the reasons a WTE facility was sited, one must go back to the information available to the project developers at that time.

A survey of 54 studies spanning over forty years of housing price assessments found results to be quite variable related to WTE facilities. Overall, they were able to ascribe a range of housing value changes from -26% to 0%. This was based off three studies: two on one facility in North Andover, MA and one in Hangzhou, China. Excluding the China study, the value range narrowed to between 0% and -3%. However, the small sample size and geographical coverage do not permit their finding to be generalized (Brinkley and Leach, 2019).

Another report focused on all 130 incinerators sited between 1965 and 2006 to determine the percentage sited in locations that were identified and coded using immigrant born populations and unemployment rates using census data. The primary hypothesis the authors developed was that incinerators are located in communities with the least political power. Using that hypothesis, the results showed that for every additional 1% of a town's population that is foreign born there was a 29% increase in chances that town would receive a WTE facility. They attribute some of that increased chance to the potential employment opportunities and the revenue-generating potential from the facility (Laurian and Funderburg, 2014).

Typical WTE facilities (i.e., processing capacity of approximately 2,500 tons per day) create approximately 600 full-time construction jobs and nearly 50 permanent full-time positions with an average annual salary over $100,000. WTE is a $10 billion industry that employs ~ 6,000 American workers with annual wages ~ $400 million and is growing worldwide and should be in the US. This is expected to continue because the WTE global market is expected to be worth $37.64 billion. There are also different industries that support WTE activities ranging from plant maintenance to supplying recyclables which provide many opportunities for residents (Atkinson, 2019).

A study that attempted to develop costs of externalities for WTE facilities concluded that due to significant inconsistency and uncertainty in the surveyed literature and analyses it is not feasible to arrive at a single "best value" (Eshet, Ayalon and Shechter, 2005). Therefore, it is recommended that each facility location be evaluated and assessed on a case-by-case method. Like other major infrastructure projects, siting a WTE requires extensive public engagement.

The main theme that emerges from the peer-reviewed literature related to WTE facilities and environmental justice issues is that the findings vary widely, and analyses should be done for each specific facility in the location identified. Nevertheless, a survey of current locations of WTE facilities in the US shows they are in a range of socioeconomic locales and those in Europe are overwhelming located in urban (city) centers or very near them. For example, the WTE facility operating in Hempstead, NY is in an area where the median home value is $506,830. That value amounts to a median list price per square foot of $326 compared to an average of $294 for the New York-Newark-Jersey City Metro area. Another very visible example is the WTE plant located in the Paris suburb of Issy-les-Moulineaux on the riverbank Seine where it supplies heating for 80,000 households while producing 84 MW electricity. The location is one of the most densely populated places in Europe and has a median price per square foot of about $1,040. There are several WTE facilities located in industrial zones where the cost per square foot is not as high, yet there are synergies that exist making it attractive to operate there because of zoning, proximity to utility interconnections, and energy product markets.

Finally, regarding land preservation, the use of WTE occupies significantly less space compared to landfill. On average, WTE facilities require approximately 0.007 acres/ton of MSW processed resulting in a typical plant requiring about 15-20 acres over their entire lifespan. In contrast, if the same amount of waste processed in a WTE were sent to landfill for 30 years, it would require a landmass that is nearly 34% of Central Park (i.e., 280 acres) with a height of about 25 feet.

VII. WTE COMPLEMENTS RECYCLING EFFORTS

The US EPA started tracking MSW composition changes since 1960 and publishes the data in its "Advancing Sustainable Materials Management: Facts and Figures" reports. Figure 5 shows the composition changes over the past 60 years.

MSW composition is a relatively stable composition from 1960 to about 1985 except for plastic and the "other" categories. Near 1985, the increased attention on recycling led to metal, glass and plastic removal followed by the removal of paper in yard

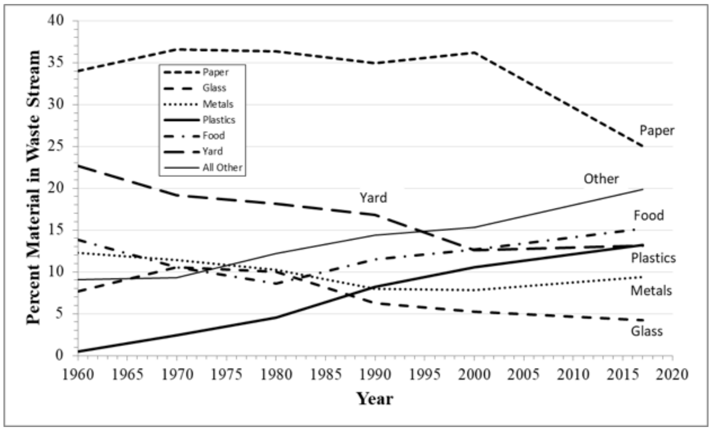


Figure 4. MSW composition changes since 1960
(Advanced Sustainable Materials Management: Facts and Figures)

waste. Another major trend observed from 1960 to the present is the continual increase of plastic waste into MSW stream. Over the years there has been a significant effort to increase recycling rates and many of them have greatly improved the overall recycling picture. However, it is clear that a significant portion of recyclable material remains in the waste stream. Moreover, the continued increase of plastic in the waste stream coincides with an increase in heating value. Therefore, there have been improvements resulting in capturing valuable recyclable material, yet the remaining portion has a significant energy content that is compatible with WTE.

Efforts to extract as much recyclable material that is feasible to process and sell must continue, recognizing that there is an upper limit. Depending on the community, it might be 40-50-60% of the MSW and will constantly change based on packaging requirements and markets. WTE is an alternative to deal with what is left that doesn't take away from sustainability and increased recycling efforts. WTE also has a unique capacity for post-combustion (i.e., post-disposal) recycling with nearly 700,000 tons of ferrous metal, 6,300 tons of aluminum, 3,400 tons of iron and 440 tons of copper being recovered and recycled.

Sustainable waste management is an increasingly important issue many municipalities are facing across the United States. Studies show the amount of waste is growing, but our recycling is not following suit. When searching for successful recycling outcomes, there are some examples in the U.S. such as Seattle, WA; Portland, OR; and Montgomery County, MD. There are also many European Union nations that achieve high levels of recycling. Less than one percent of municipal waste in many EU countries ends up in landfills. Regulatory financial taxes have been put in place on landfilling organic waste materials in the EU and UK; these provide the economic incentive to divert and process MSW leaving little unprocessed non-organic waste left for landfilling. This has resulted in being able to implement successful reuse, recycling, composting, and WTE programs while relying less on landfilling.

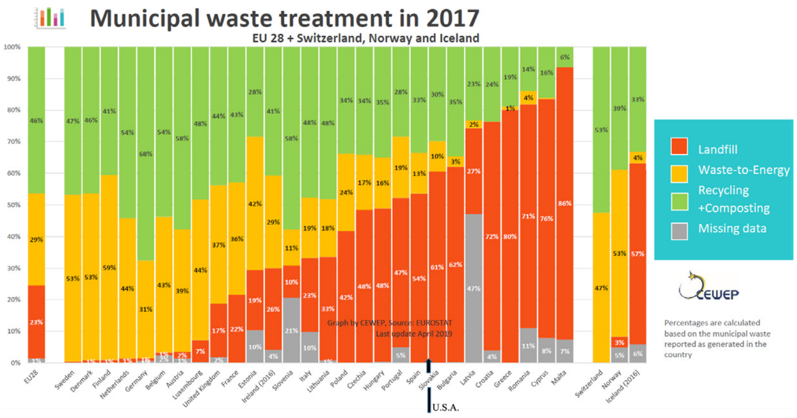


Figure 5. Comparison of waste management options demonstrating
WTE diverts waste from landfills, not recycling

Taking a closer look at the EU, it becomes clear that WTE is used only to process residual waste, i.e., waste that is not targeted for recovery through reuse and source-separation recycling. Therefore, it does not

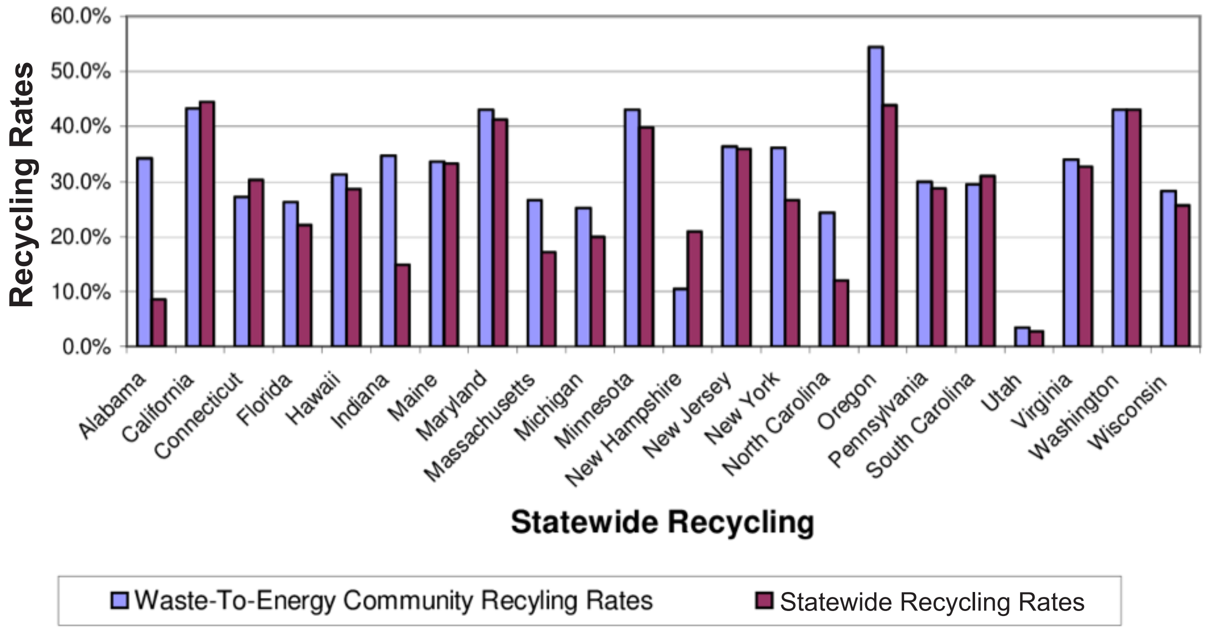


Figure 6. Data showing U.S. communities that employ WTE have similar or higher average recycling rates compared to statewide(Berenyi, 2009)

compete for materials that can be recovered and sold through source separation recycling. In fact, data from WTE communities in the U.S. and abroad where recycling programs have been put in place has consistently demonstrated this point. Figure 5 contains data from European WTE countries where the use of WTE correlates positively with increased recycling and reduces the amount of waste that is landfilled. The U.S. has the requisite wealth, technology and skilled workforce to achieve sustainable status equivalent to environmentally focused countries such as Sweden, Denmark, Germany and Belgium. Instead, the U.S. currently manages their waste like Slovakia and worse than Poland and Hungary.

U.S. counties and municipalities that utilize WTE consistently show an increased recycling rate.

Moreover, U.S. counties and municipalities that utilize WTE consistently show an increased recycling rate. Figure 6 demonstrates that communities in the U.S. that employ WTE achieve better recycling rates than their non-WTE counterparts. These examples, as well as numerous other studies unambiguously demonstrate that WTE is compatible (Berenyi, 2014; M.J. Castaldi, 2014; Brunner and Rechberger, 2015).

Despite some assertions to the contrary, WTE facility operators are not economically incentivized to source recyclables as a feedstock for combustion. The higher energy content of recyclables like paper and plastics relative to mixed municipal solid waste actually reduces facility revenues. WTE facilities are generally limited by the amount of steam they can make, and in turn, the amount of heat energy that can be fed into the boiler in the form of waste materials. Taking additional or bulk quantities of high heat content materials, like paper and plastics, reduces the amount of waste that a typical WTE facility can process. Since most WTE revenues come from waste tip fees, revenues would decrease from taking in large amounts of paper and plastics.

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ACKNOWLEDGMENTS:

- Photos courtesy of Covanta, ecomaine, Solid Waste Authority of Palm Beach County and WIN Waste Innovations, formerly Wheelabrator Technologies
- Special thanks to Steve Faber, Byrum & Fisk Communications, for final design and editing. www.byrumfisk.com

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The Materials & Energy Recovery (MER) Division of ASME supports this document and is aligned with the findings.

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