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.

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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.

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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).

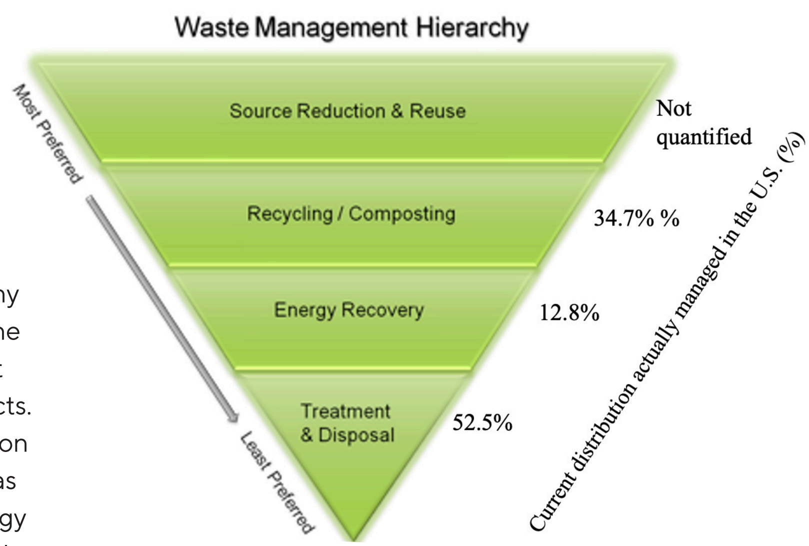

Figure 1. Sustainable Waste Management Hierarchy. (source USEPA)

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. 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

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).

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 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

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."*

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.

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.

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

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.

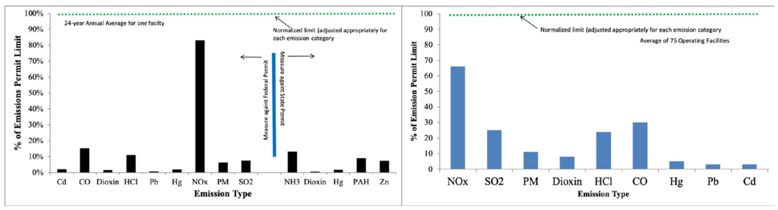

Figure 3. Emissions compared to federal and state limits. Left; results of an average of 70 operating facilities in the U.S. Right; Average stack emissions for 2019 and 25 years of operation for one facility

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 0.061×10^{-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 flue gas 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

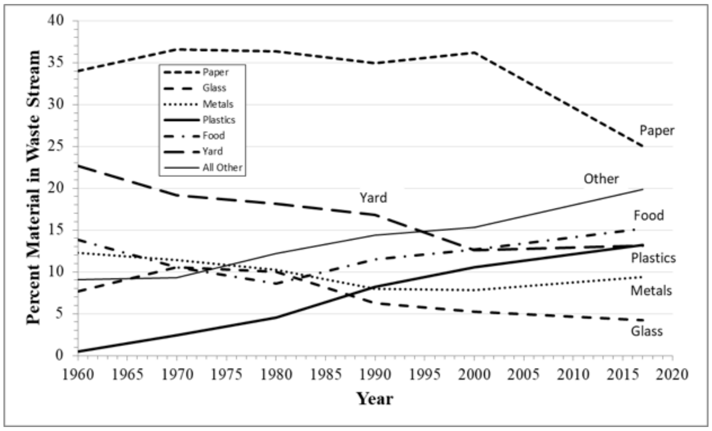

Figure 4. MSW composition changes since 1960
(Advanced Sustainable Materials Management: Facts and Figures)

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.

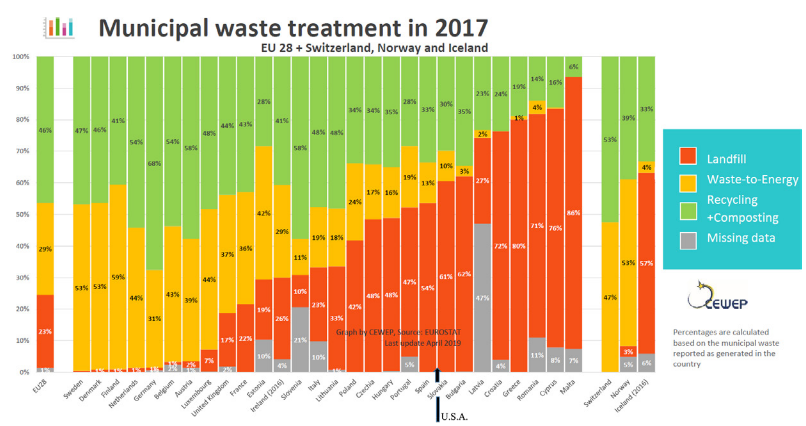

Figure 5. Comparison of waste management options demonstrating
WTE diverts waste from landfills, not recycling

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

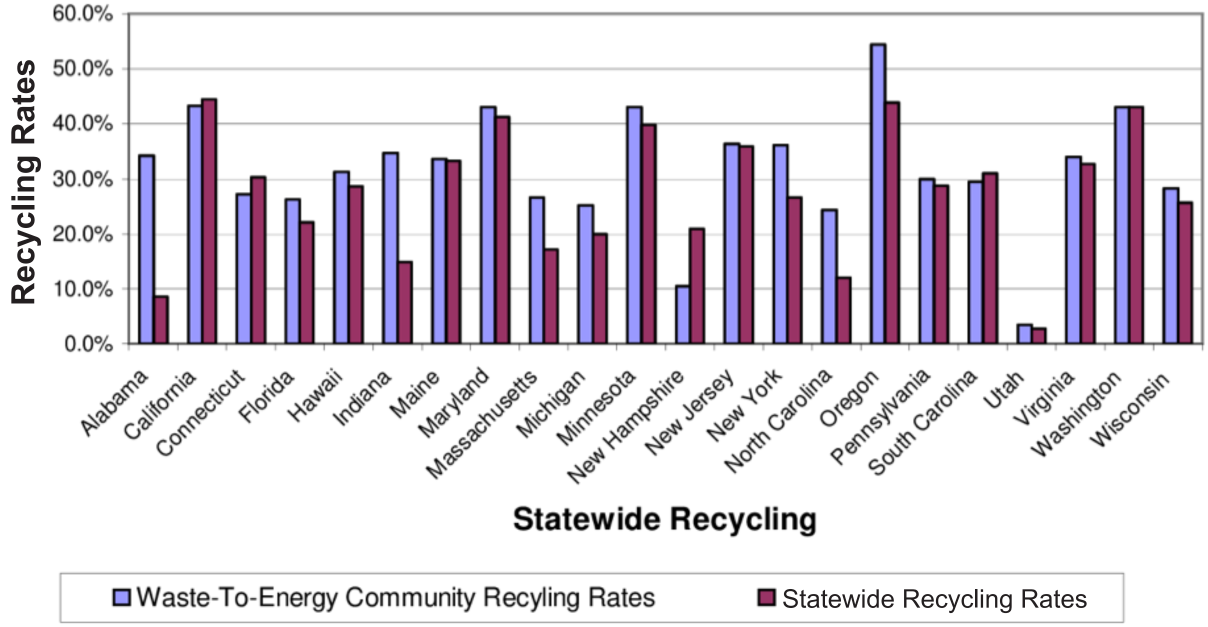

Figure 6. Data showing U.S. communities that employ WTE have similar or higher average recycling rates compared to statewide(Berenyi, 2009)

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.

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.

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

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MATERIALS &
ENERGY RECOVERY
DIVISION

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

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