Impacts of Scale on Food Waste Technologies:
An Analysis of Three Technology Options for the City of Minneapolis

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Executive Summary

The city of Minneapolis has expressed interest in becoming a zero waste city. In order to do so the city will need to consider outlets for food waste. Consumer level food waste in the United States is contributing to a number of environmental issues on the global, regional, and local level. While reductions to this waste stream will help mitigate these effects, food waste will never be completely eliminated and there are a number of technologies that makes it a useful resource. This paper will describe three technology options (waste-to-energy, composting, and anaerobic digestion), stakeholders involved in waste management, and three case studies that have experience with these technologies and food waste to form policy implications for the city of Minneapolis. These three considerations will help contextualize some of the policy options that have been used already and how they could impact future decisions in food waste management.

Minneapolis currently uses waste-to-energy and composting facilities for waste management. Waste-to-energy facilities can process all forms of waste, but food negatively impacts energy generation from incineration. Composting is better suited for food waste, but is not the only technology suitable for this waste stream. Anaerobic digestion is a technology that is able to process food waste, while also creating biogas that can be used for heating, electricity, and transportation, and is currently not used by Minneapolis. All three technologies are promoted differently at the national, state, and local scale making goal setting and policy making that impacts food waste a challenge for cities. Further the combination of public and private waste management programs complicate who should be investing in these technology options.

Support of these technologies differs at various scale of governance. Waste-to-energy is considered a last resort for food waste at the federal and state level. The EPA promotes anaerobic digestion over composting, but the opposite is true for the state of Minnesota, which impacts decision making at the county and city level. Currently, changes to food waste management in Hennepin County are mostly happening through curbside composting programs and commercial composting due to funding and support from the state. While the state is researching the effects of anaerobic digestion, they may be missing an opportunity to invest in an equal if not better suited technology for food waste. This raises questions about who should be setting waste management goals and how stakeholders can work together to attain them. Further, waste management goals from the state level are guiding policy decision at the local level, but policies that target waste are not always yielding positive results. Ultimately these differing recommendations from each level of government create a confusing environment for stakeholders in waste management.

Introduction

The entire food supply chain wastes a third of its production (FAO, 2013) and has a surprising impact on climate change. If food waste were a country, it would be the number three greenhouse gas emitter behind China and the United States (FAO, 2013; see Figure 1A), representing 8% of total anthropogenic carbon emission. The creation of food waste occurs during production, postharvest handling, processing, distribution and consumption of food, and there are discrepancies in waste-generation patterns globally. The problem in the developing world is food loss, where improper storage and handling spoils food before it can even be purchased. The industrialized world has a bigger contribution from consumer level food waste (Royte, 2014; see Figure 1B). The average American family throws out 25% of the food it purchases, an estimated annual loss of $1,365 to $2,275 per household (NRDC, 2012). For the United States, it is important for food waste initiatives to address the consumer waste stream.

Food waste is a policy concern for a range of governance scales because the impacts exist at a number of spatial scale. Globally, the contribution of food waste to climate change is significant, making it a good place to intervene to reduce carbon emissions. However the creation and management of food waste exists on a local and regional level. Some management strategies are more impactful than others and there are a number of problems food waste can help solve: food can be redistributed to reduce hunger, converted to energy to divert use of coal and oil, or composted to supplement and replace fertilizer use. Furthermore, everyone is responsible for creating food waste, so solutions that depend on waste reduction require behavioral change from entire populations. Finally, the increasing costs of and limited space for waste disposal make the case for repurposing food waste. However, because there are a number of technology solutions for food waste, the costs of these technologies are expensive, and relevant actors have conflicting views on which technology is the most appropriate and waste management generally. Therefore these technologies would benefit from policy interventions that acknowledge them as solutions for consumer food waste.

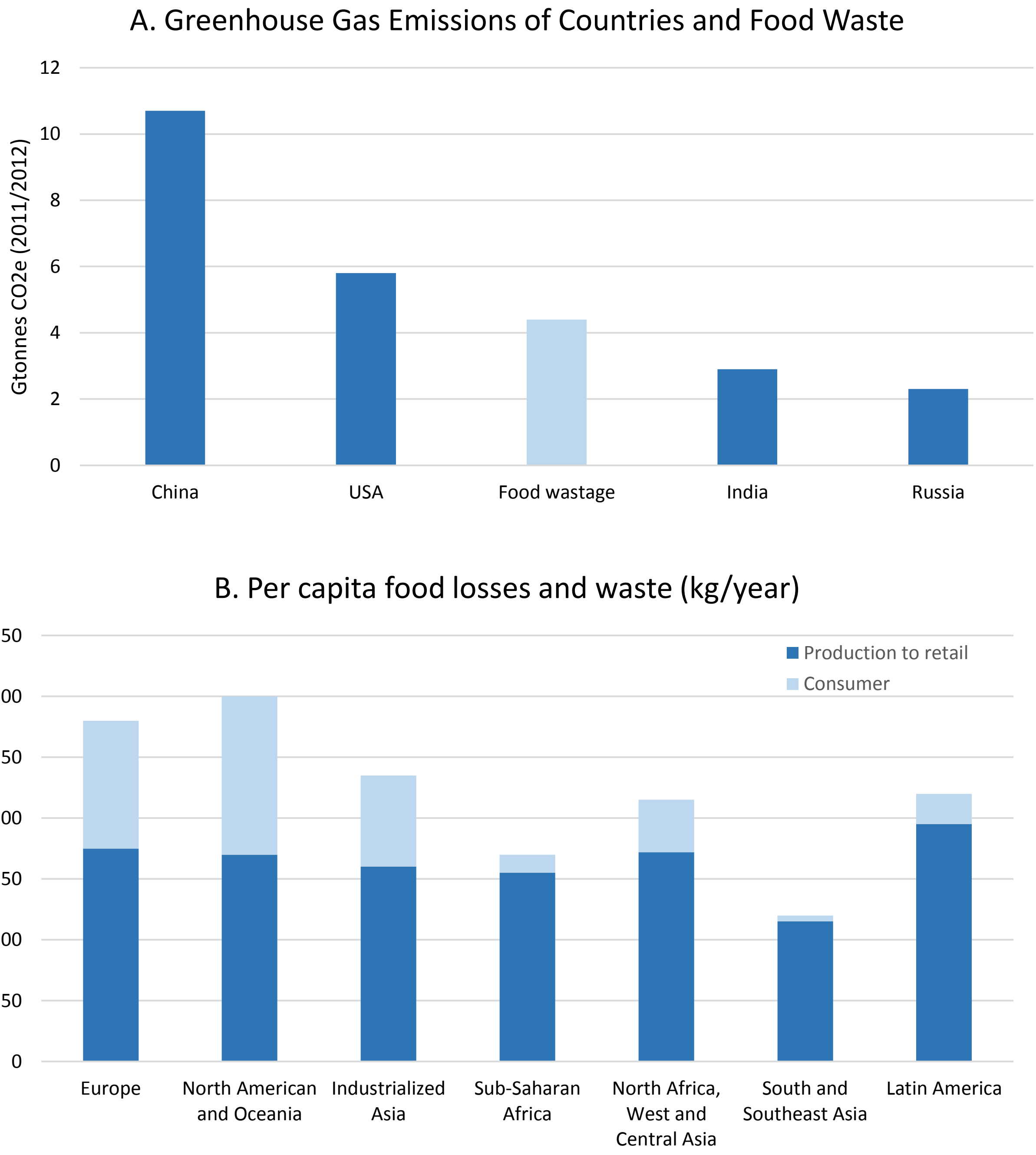

Figure 1. A. Greenhouse Gas Emissions of Countries and Food Waste. Data retrieved from WRI, 2015. B. Per Capita Consumer Level Food Waste. Data retrieved from FAO, 2011.

The EPA has created a Food Recovery Hierarchy that ranks outlets for dealing with food waste (EPA, n.d.; see Figure 2). When it comes to technologies, the EPA prefers industrial uses for food waste, such as energy recovery over composting. These recommendations differ slightly from some state recommendations, which remain unsure of the effectiveness of industrial uses and prefer municipal composting (MNPCA, 2017). State plans and recommendations for municipal solid waste and food waste guide regional and city level policy and planning in these areas.

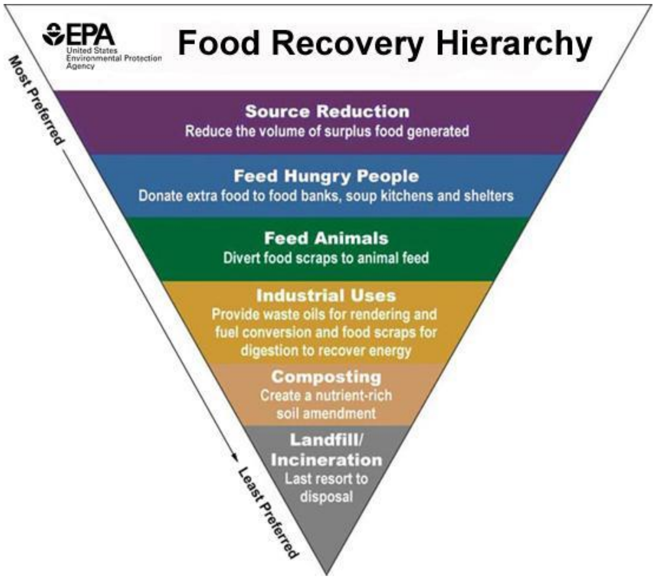

Figure 2. EPA Food Recovery Hierarchy

There are three popular methods for diverting waste from landfills, and some are more appropriate for food waste than others. Waste-to-energy facilities incinerate waste that is used for district heating and electricity; composting is used to divert exclusively food and organic waste from landfills while producing a fertilizer substitute; and anaerobic digestion decomposes food waste to produce energy. There are advantages and disadvantages to each method that will be presented through literature review, stakeholder analysis, and a relevant case study to help inform policy makers of Minneapolis interested in reducing the impacts of our food waste and some of the conflicts that exist at different levels of government.

Technology Options

Residential and commercial trash is referred to as municipal solid waste and can be processed at a number of facilities that dispose or recycle this waste. These facilities generate revenue from tipping fees, which is the cost to dispose of waste on a weight basis and can be publically or privately owned. With the space of landfills decreasing, tipping fees at these facilities have increased significantly, encouraging other outlets for waste (Layzer and Schulman, 2014). Food waste has become a focus of waste management policy because it makes up a sizeable volume of municipal solid waste that needs to be managed differently for cities and states to reach waste reduction goals. Some of the technologies that prevent landfilling include waste-to-energy, composting, and anaerobic digestion, which are advantageous for different waste streams. Specifically for food waste, some technologies make more sense than others.

1. Waste-to-energy

Burning municipal solid waste to circumvent landfills started in the 1960s and 1970s (Miranda and Hale, 1997). In the beginning, energy generation from waste incineration was not typical until high oil prices in the 1970s motivated development of alternative energy sources (Funk, Milford, and Simpkins, 2013). These facilities were quite polluting until more stringent regulations were set in the 1990s. Despite the improvement to environmental and human health, waste-to-energy (WTE) plants have stalled. There are 71 WTE plants in the United States, none of which were built within the last 10 years (Funk et al., 2013). In 2015, 29 million tons of waste, representing 13% of municipal solid waste generation, was incinerated for energy generating 14 billion kWh of electricity (EIA). Sixty-four percent of this waste was biomass that could have been diverted for organic recycling.

WTE plants have a number of advantages over landfilling municipal solid waste. These facilities reduce both the volume and mass of waste while also generating heat and steam energy (EIA, 2007, see Figure 3). This energy production substitutes for fossil fuels: one metric ton of municipal solid waste is able to generate 600kWh of electricity, offsetting the need for a quarter ton of coal (Psomopoulous et al., 2009). WTE facilities also have a much smaller land footprint than a landfill that would accommodate the same quantity of waste (Psomopoulous, et al. 2009).

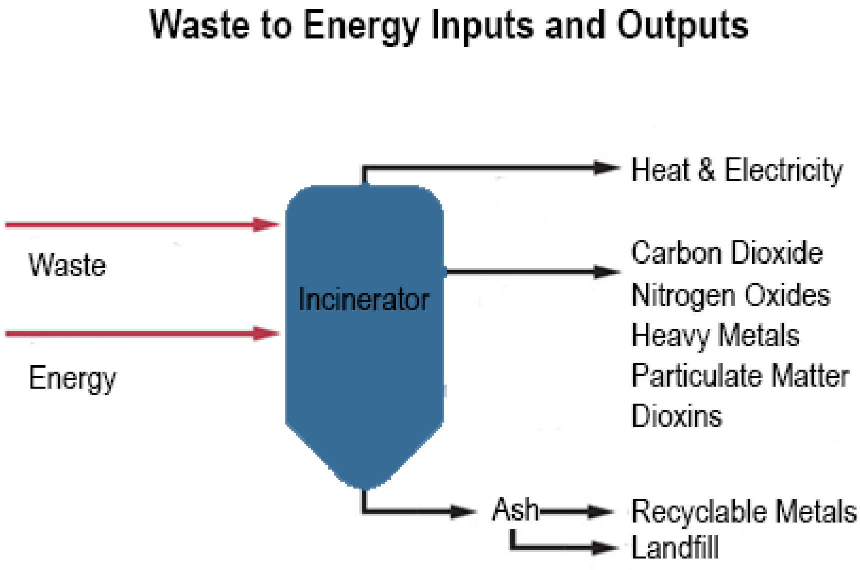

Figure 3. Waste-to-energy Inputs and Outputs

WTE plants fall into two categories: mass-burn and refuse-derived fuel. Mass-burn plants make no effort to separate waste and feed a stream directly into a furnace with little preparation (Psomopoulous et al., 2009; Themelis and Reshadi, 2009; Miranda and Hale, 1997). The benefits of this method is its simplicity and low cost. These plants are more commonly found representing 77% of US plants and 90% of global WTE plants (Themelis and Reshadi, 2009). Refuse-derived fuel plants process waste prior to burning. Low caloric waste, such as glass, plastic, and often food, is removed and the remaining waste is shredded and processed to create a fuel. This increases the capacity of the combustion unit. Because of the increase in technological capabilities, refuse-derived fuel plants are more sensitive and require more labor to operate (Themelis and Reshandi, 2009).

Both types of plants produce leftover material called bottom and fly ash that is 10% of the original volume and 24% of the original weight (Miranda and Hale, 1997). This material is generally processed again to remove ferrous and non-ferrous recyclable materials before discarding (Zakariak and

Sutin, 1994). Europe often uses it for road aggregate, fill material, or to substitute for cement (Miranda and Hale, 1997); otherwise it is used as a landfill cover.

WTE plants are regulated by the Maximum Achievable Control Technology standard in the 1990 Clean Air Act Amendments. These standards require technologies such as dry scrubbers, fabric filter baghouse, and activated carbon injections (Psomopoulous et al., 2009) that reduce particulate matter and emissions of hydrogen chloride, sulfur dioxide, mercury, and nitrogen oxides (Miranda and Hale, 1997). The implementation of these standards have significantly reduced emissions of WTE facilities, resulting in a 94% drop in emissions of hazardous air pollutants from 1990 to 2005 (EPA, n.d).

WTE facilities have advantages and disadvantages over the energy sources that they can replace, such as coal and natural gas. WTE facilities release less sulfur dioxide and nitrogen oxide emissions than coal-burning facilities, but more than natural gas (Psomopoulous et al., 2009). Incinerating waste produces more greenhouse gases per MWh than coal and natural gas (Morris, 2010), however life cycle emission analysis calculate WTE below coal and natural gas emissions when biogenic material emissions are subtracted out (EPA, n.d.) This is because biogenic sources of emissions that WTE facilities process are already counted in the carbon cycle and would exist regardless of how they decompose. Although most studies cite WTE as a strategy for reducing carbon emissions from landfilling and fossil fuel combustion, the rate at which emissions are reduced is heavily dependent on waste composition, source of energy replaced, and whether landfills capture methane production for energy (Jeswani, Smith, and Azapagic, 2012).

This highlights the controversy of how to count emissions from these facilities. The EPA argues that CO_2 emissions from biomass and organics should be considered carbon neutral, as these are products that would be a part of the carbon cycle, and would emit the same amount of carbon and carbon equivalent emissions over the span of several decades, instead of immediately when harnessed for energy (Baptista and Amarnath, 2016). The United Nations Environment Program takes a different view stating,

"…the atmosphere does not differentiate between a molecule of biogenic CO_2 and a molecule of fossil-derived CO_2, therefore it appears logical that immediate efforts should be made to minimize emission of all CO_2 regardless of source" (UNEP, 2010). While the United Nations recognizes WTE as a useful approach in mitigating climate change, as they are comparatively much less impactful than landfilling, they are conscious of the carbon impact these facilities have.

An important consideration of WTE sites is their public appeal. The EPA and 21 states consider WTE a renewable energy source (Jossi, 2016; Baptista and Amarnath, 2016), but some see investment in WTE before recycling as a disregard for the hierarchy of waste. WTE is also quite unpopular in the United States due to environmental and health risk perceptions based on the effects of facilities before regulations (Miranda and Hale, 1997). Current health studies have detected higher concentrations of heavy metals and organic chemicals in areas surrounding incinerators, however there has been no causal link to negative health outcomes (Glusti, 2009). Further, there are few studies on how technology improvements to facilities may reduce negative health outcomes. While the actual risks may not align with the measured health impacts, it is important to consider where facilities are built and the implications on environmental justice. Often WTE facilities are located near other industrial sites that are within or in close proximity to neighborhoods with high concentrations of low-income people of color. Because of this they are targeted by the environmental justice movement (Pulido, 2000).

2. Composting

Composting requires oxygen to facilitate the "decomposition of organic materials by microorganisms" (ILSR, 2014). There are 4,914 composting sites in the United States, 71% of which only accept yard waste. Most of these facilities are also very small scale, processing less than 5,000 tons of organics per year. The lack of facilities makes it hard for municipalities to develop composting programs. In 2013, there were only 183 communities in 18 states that had curbside composting (Layzer and Schulman, 2014).

Composting is the step above landfilling on the EPA Food Recovery Hierarchy. In the United States, composting of food waste grew slightly from 1.84 million tons in 2013 to 1.94 million tons in 2014, 5.1% of our food waste (EPA, n.d.). The primary benefit of composting is the diversion of food waste from landfills, where it would decompose anaerobically to emit methane. Composting can also save municipalities money depending on tipping fees of landfill and compost facilities (Layzer and Schulman, 2014). However, composting is an energy consumer, requiring 30-35 kWh per ton of waste to operate (Hartmann and Ahring, 2006).

The inputs for composting are organic material, air and water, and the outputs are compost, heat, water vapor, and carbon dioxide (see Figure 4). Sites can range in scale from backyard systems to large scale industrial units. Facilities that can accommodate municipal levels of waste are thermophilic aerated systems, which incorporate additional heat in the process (Farrell and Jones, 2009). There are two kinds of thermophilic aerated systems: turned or forced aeration. Turned systems are fairly simple, organic waste is piled and occasionally turned to inject oxygen and moisture and release air. Forced aeration systems operated similarly, but have more advanced technology monitoring the system (Farrell and Jones, 2009). Waste goes through three stages: sanitization, biodegradation, and a tertiary stage. Sanitization uses heat to breaks down pathogens, biodegradation cools the waste to stimulate waste decomposition, and the tertiary stage reduces potentially harmful byproducts such as ammonium, nitrates, and volatiles and stabilizes microbes.

Composting is a time intensive process, taking 30 to 45 days to complete (Farrell and Jones, 2009). Quality of compost depends a lot on the inputs and timing. If the final stage is not fully completed, contaminants remain in the compost, making it unusable for plants. Pathogens can also develop from improper management, particularly if the timing, temperature, or mixing of waste is off (Farrell and Jones, 2009). In order for compost to be used as a fertilizer supplement, it has to be free of physical contaminants. Plastics are often mixed in with post-consumer food wastes and are released back into the environment when used as fertilizer.

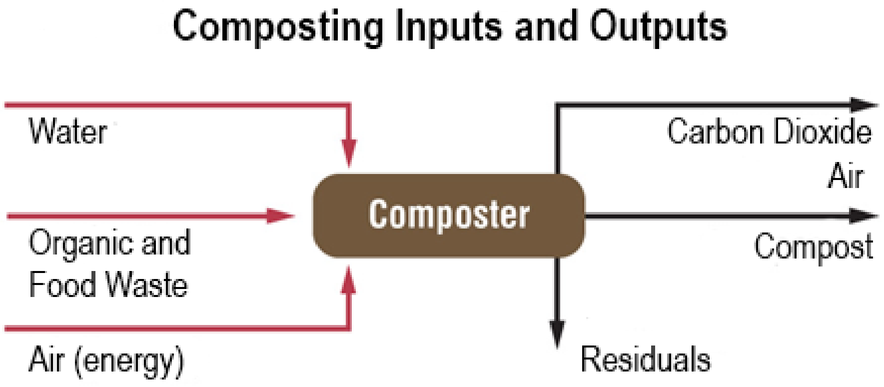

Figure 4. Composting Inputs and Outputs (Kraemer and Gamble, 2014)

Organic waste for composting can be derived from source separated waste or done post-disposal at composting facilities. Waste that is sorted post-collection often has contamination issues from salt and metals that make it a poor substitute for fertilizer (Hargreaves, Adl, and Warman, 2007). These pollutants can be taken in by crops and inhibit plant growth or leach into groundwater sources. A poor quality compost is not recommended for use in agriculture, but can be used as a cover for closed landfills, which can help contain and reduce methane emissions (Lou and Nair, 2009). However, the effectiveness of this strategy is dependent on a many factors as well and may not be suitable in colder climates.

Composting facilities can also produce unpleasant smells, and are hard to site in an urban setting (Farrell and Jones, 2009). Opposition to sites has come from residents and environmental groups concerned about air pollution and asthma. However when sites are not located nearby, the environmental benefit of composting is often offset by the emissions from transportation (Foth, 2013). Other reasons for opposition come from residents opposed to the additional monthly costs for municipal curbside composting (Bryen, 2015).

In general, composting is found to be less greenhouse gas intensive than landfilling waste (Lou and Nair, 2009). When properly managed, there are a number of benefits that make composting an attractive solution for dealing with food waste. However, it is necessary to separate food from other waste streams to reduce the environmental issues that municipal solid waste compost creates.

3. Anaerobic Digestion

Organic waste, particularly food waste, has energy potential that can be harvested through anaerobic digestion. Anaerobic digestion is a biological process that uses microorganisms to break down biodegradable materials in the absence of oxygen (American Biogas Council). Anaerobic digestions in the United States have typically been used at wastewater treatment plants and as a manure management strategy on dairy farms. China, India, and Southeast Asia have been developing small scale digesters to process municipal solid waste, animal waste, agricultural waste, and food production waste to address problems with growing populations and waste burning. Many of these sites now generate electricity with the biogas produced from these facilities (Klinkler, 2014). Europe has developed anaerobic digesters for similar reasons, but at a larger scale (Cal Recycle, 2013).

Because organic waste has such a high moisture content, it is often improperly suited for WTE and reduces the effectiveness of energy production. Composting has been used to divert this waste stream, but consumes energy, while anaerobic digestion is an energy producer. Anaerobic digestion has become a popular alternative energy source because it reduces the strain and emissions of municipal solid waste operations and landfills, produces valuable agricultural fertilizers, while simultaneously producing energy from a renewable, yet limited and contentiously labeled source (Hartmann and Ahring, 2006).

Inputs must be filtered for metals and plastics and there are a number of processes to pretreat waste to improve energy productivity (Zhang, Hu, and Lee, 2016). Waste, energy, and water are the inputs to the digester (see Figure 5). The system begins with a hydrolysis phase, where bacteria break down insoluble organic polymers (carbohydrates), to be processed by other sets of bacteria (American Biogas Council). The next stage is fermentation, which converts the sugars and amino acids into carbon dioxide, hydrogen, ammonia, and organic acids. A third set of bacteria convert the remaining organic acids into acetic acid. The final stage, methanongenesis, converts these acids to methane and carbon dioxide. This creates biogas which can be combusted to generate electricity, heat, and substitute for natural gas and gasoline (Hartmann and Ahring, 2006).

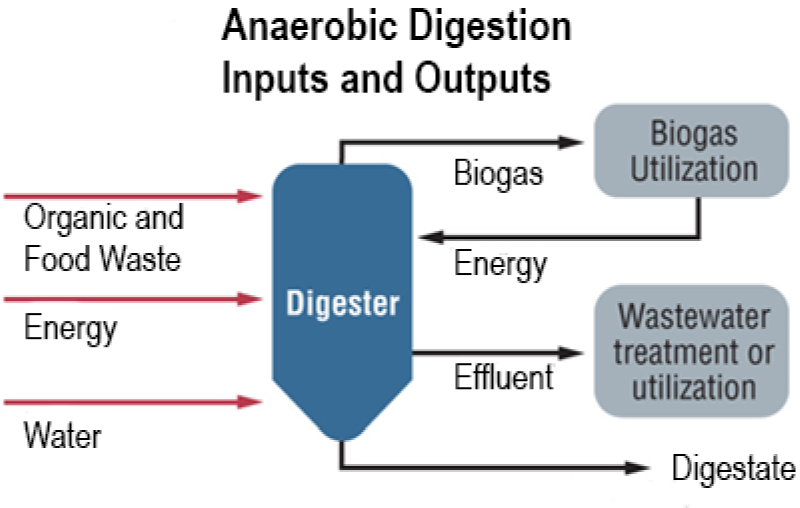

Figure 5. Anaerobic Digestion Inputs and Outputs (Kraemer and Gamble, 2014)

Biogas is a very versatile product depending on treatment processes. The biogas that is produced is a mixture of methane and carbon dioxide and can be transported directly to a gas use device, upgraded to use in natural gas pipelines, or substitute as a vehicle fuel. Anaerobic digestion also produces a digestate that is usable with further processing to separate the solid and liquid components. The liquids can be used as a low grade fertilizer, while the solids can be composted (Moriarty, 2013). Mixing the digestate into degraded soils will restore them to an organic rich state that can further reduced the CO_2 imbalance by absorbing some of it out of the atmosphere (Mata-Alvarez, 2000).

Anaerobic digestion facilities face a lot of similar concerns that composting sites have: odor, traffic, and noise (MAPC, 2014). Additionally, because anaerobic digestion creates energy, there are concerns that crops will be grown for energy production and compete with land for food production. The United Kingdom’s arable crop land devoted to purposefully grown crops is expected to increase because of anaerobic digestion, though at a very small rate (Roder, 2016). Germany's subsidies for biogas have resulted in significant changes in land use outside of the EU where crops are being grown for fuel and not food (Britz and Delzeit, 2013). Land use is a potential concern, but it is hard to predict without knowing policy incentives for producing biogas through anaerobic digestion.

Methods

My study will create a framework for comparing waste-to-energy, composting, and anaerobic digestion by assessing local, regional, and global tradeoffs of each technology and how they improve on the default of landfilling. The framework will consider pollution impacts, effectiveness with food waste, and community acceptance on the local scale; energy production, byproducts, and municipal solid waste reduction on the regional scale; and carbon footprint on the global scale. Actors and stakeholders will be evaluated for how interests may be influenced by the scale they exist in. Finally, I will use three case studies for each technology option to investigate the factors that impacted policy and technology choices. I will use the framework, stakeholder considerations and the history of the case studies to make policy recommendations for the city of Minneapolis to consider in dealing with food waste and how these technologies could be useful.

Technology Considerations – Costs and Benefits, Stakeholders, and Case Studies

To make choices about municipal solid waste and food waste policy, it is important to consider some of the costs and benefits of each technology and how they compare to the default of landfilling. WTE, composting, and anaerobic digestion are all better options that landfilling, but have tradeoffs that exist at local, regional, and global scales. Knowing these costs and benefits are important to inform technology choices, but also to understand how stakeholders that exist at these scales support certain technology choices and how that is reflected in policy and waste management planning. The recommendations of stakeholders from higher levels of governance could impact policy decisions made at the local level, even if a different technology options may be better suited for local waste management. Finally, there are examples of policies and technology development that have already been implemented and can shed light on outlets for policy change and technology choices. Using a spatial framework will highlight how the complexity of technology impacts stakeholder decision making theoretically and in practice. This section will describe the benefits of WTE, composting, and anaerobic digestion over landfilling and the tradeoffs between each technology, layout general stakeholders that have interest in these technologies, and consider a case study that represents each technology option to learn from previous attempts at mitigating the impacts of food waste.

1. Costs and Benefits at Multiple Scales

WTE, composting, and anaerobic digestion have differing tradeoffs that exist at local, regional, and global scales (Table 1). These are technologies are all options to manage waste, or more specifically food waste that are often promoted over landfilling, the default option if they are not developed. The complexity of the costs and benefits of these technologies have an influence on governance agencies that exist at local, regional, and global scales. They are not technologies that are mutually exclusive; they can be used in tandem to deal with specific waste streams if streams are separated.

WTE has more local and global environmental impacts, less public support, and is not very effective with food waste. Food waste also contributes to the negative impacts of WTE facilities; it is the main input that causes hydrogen chloride production in waste incineration (Hartmann and Ahring, 2006), one of the primary pollutants of concern. Food and organic waste also have a very high moisture content that decreases effectiveness with WTE (Zhuang et al., 2008). The heat value of organic waste improves with dehydration, but this requires source separation.

Anaerobic digestion and aerobic composting are both processes that are more effective with food waste, but anaerobic digestion has some advantages over composting. Anaerobic digestion produces

Table 1. Tradeoffs at Various Spatial Scales of Waste Technology Options

Scale	Consideration	Landfilling	Waste-to-energy	Composting	Anaerobic Digestion
Local	Community Acceptance	Low	Low	High – though dependent on placement of compost facility	Medium
	Pollution Impact	Leachate, carbon dioxide, methane, volatile organic compounds, heavy metals, synthetic organic compounds (Giusti, 2009)	Nitrogen oxides, mercury, sulfur dioxide, hydrogen chloride, particulate matter, dioxins (Hennepin County, 2011)	Ammonium, methane, nitrogen oxides, volatile organic compounds, leachate (composition dependent on application site), odor (Chatterjee et al., 2013)	Methane Removal through treatment - Hydrogen sulfide, siloxanes, moisture, particular matter, ammonia, carbon dioxide (Kuo, 2015)
	Effectiveness with Food Waste	Low	Low	High	High
Regional	Byproducts	None	Ash – extracted for recyclable metals and landfilled (Pham, 2015)	Compost (Khoo et al., 2010)	Digestate - used as fertilizer if properly treated (Pham, 2015)
	Energy Production	With energy capture: electricity, heat (EPA, n.d.)	Heat, electricity (Pham, 2015)	None	Biogas burned for heat and electricity (Pham, 2015)
	Municipal Solid Waste Reduction	None	90% (Covanta SEMASS, n.d.)	40% (Breiten beck and Schellinger, 2004)	10-98% (Macias-Corral et al., 2008)
	Capital Costs	$336,000/acre (EPA, 2014)	$600-700/ton municipal solid waste (Themelis and Reshadi, 2009)	$75/ton of organic waste (van Haaren, 2009)	$561/ton of organic waste (Moriarty, 2013)
Global	Carbon Footprint	No energy capture: 1167.g kg CO2e/ton of municipal solid waste (Lou and Nair, 2009) Energy capture: 358.3 kg CO2e/ton MSW (Jeswani et al., 2013)	-117.9- 208.7 kg CO2e/ton municipal solid waste (Jeswani et al., 2013)	-134-58 kg CO2e/ton of food waste (Levis and Barlaz, 2011)	-315 kg CO_2e/ton of food waste (Kim et al., 2013)

methane that can be used as an energy source which is not captured from composting (de Barere and Mattheeuws, 2015). Further the benefits of composting are very site specific and dependent on organic waste inputs (Lou and Nair, 2009). If organic waste is not source separated, machinery is required to produce high quality compost. Additionally, composting produces volatile compounds that can be large and uncontrolled; anaerobic digestion minimizes and controls these emissions (Mata-Alvarez, 2000). Finally, it is a much more contained process that minimizes odor nuisance (de Barere and Mattheeuws, 2015). Life Cycle Assessments of incineration, composting sites, anaerobic digesters, and aerobic/anaerobic combination sites give anaerobic digesters the advantage because of energy production (Mata-Alvarez, 2000).

Expansion of composting and anaerobic digestion is a challenge if there are few or no available facilities because of transportation and capital costs. Cities have cancelled their composting pilot program because of the expense of hauling organic waste miles outside of the city (Layzer and Schulman, 2014). Cities have felt that if a facility was closer it could be a successful program. However, siting a composting facility within a city would be a challenge because of the size, increased traffic, and associated odors. Odors can be reduced with more advanced, closed system technology but public perception driven "Not In My Backyard" attitudes could prevent development of facilities (Layzer and Schulman, 2014).

Anaerobic digesters could also face similar issues as composting facilities because of the perception of odor and increased traffic. Anaerobic digesters are also sometimes available through under-capacity wastewater treatment plants or dairy farms and could be a potential outlet for food waste (Mata-Alvarez, 2000). When it comes to environmental impacts and energy production, anaerobic digestion is seen as the best route for managing organic waste. However the technology is not fully supported at all governance levels (MPCA, 2017).

2. Actors and Stakeholders

Food waste initiatives and relevant technology options have stakeholders at global, national, state, regional, and local levels of governance (see Figure 6). These scales have public and private interests that will impact technology decisions, but also differing recommendations depending on which scale is impacted by the costs and benefits. Food waste reductions goals differ at each level. Global (UN FAO) and national (USDA and EPA) standards have a goal to halve food waste by 2030 from 2015 levels (UN FAO; St. Clair, 2015). State and regional levels do not necessarily have explicit food waste reduction goals but do set recycling goals. At the local level, zero waste goals have become popular for cities to state in their planning.

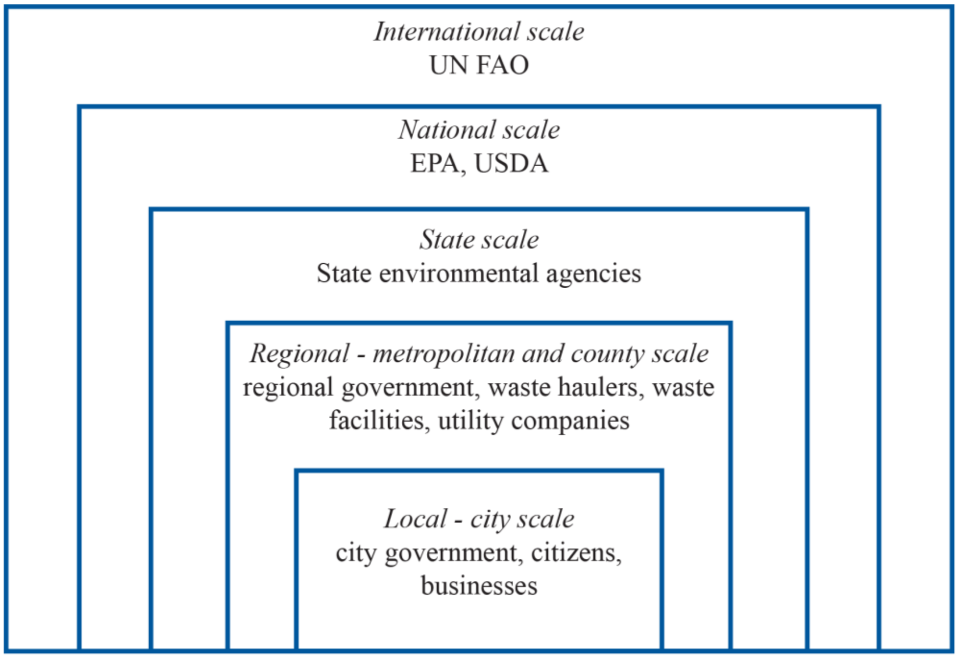

Figure 6. General stakeholder scales

Often the explicit policies that mandate diversion of food waste have been enacted at the state and local level. This means that choices on appropriate technologies for managing food waste are very much a local decision. However, it is not necessarily a local *public* decision, as municipalities often contract out portions of waste collection to private companies. Further, the facilities that collect waste from these companies are both private and publically owned. Because of the public and private nature of waste collection, it is not a guarantee that waste will be diverted to the publically desired location as counties and municipalities by law cannot dictate where private waste haulers bring their waste (Office of Legislative Auditor, n.d.). However, as landfill tipping fees have increased, private companies may be more compelled to haul waste elsewhere.

These waste reduction goals have to consider both public and private waste collection facilities that would accommodate new streams of waste. If there are too few facilities, it may be necessary to develop new disposal sites. Waste management sites often have strict regulations to determine that the land is suitable for it. Sites dealing with organic materials often have less strict regulations, provided the site would not be considered a public nuisance or present a threat to health and safety, which can make these facilities easier to site (Fitzgerald, 2013). There may already be under-capacity facilities, such as wastewater treatment plants that would benefit from taking on food waste.

Finally, energy production from waste must consider utility companies' policies on buying from these energy sources. Renewable gas standards differ from state to state, which can make it harder to sell biogas from anaerobic digestion, and some utility companies have questioned the safety of biogas (Johnston, 2014). When excess fuel cannot be sold to utilities, methane is flared off, releasing the emissions that would be contained by digestion.

3. Case Studies

Case studies are helpful to better understand how previous attempts with waste to energy, composting, and anaerobic digestion and supporting policy have addressed food waste. The Southeastern Massachusetts Resource Recovery Facility in Rochester, MA is a well-regarded WTE facility, but the state of Massachusetts has still implemented policy to divert food waste to composting and anaerobic digestion. San Francisco has some of the strictest food waste bans in the country that has resulted in citywide composting. Despite this they have had some problems with increased landfilling of waste.

Finally, the East Bay Municipal Utility District utilized an under-capacity anaerobic digestion for food waste and found that energy production improved. These case studies were chosen because of they are examples of technology changes, rigorous policy, or successful experimentation that deals with food waste and help contextualize these technology options.

Waste-to-energy: Southeastern Massachusetts Resource Recovery Facility

The Southeastern Massachusetts Resource Recovery Facility (SEMASS), owned by Covanta, opened in 1988 in Rochester, MA (Covanta SEMASS, n.d.). The facility is 95 acres and processes over one million tons of municipal solid waste, one fifth of total waste generated by the state of Massachusetts. This facility is praised as a successful refuse-derived fuel plant. The facility processes both wet and dry municipal solid waste by sending it through a shredding stage to make an even particle size, which reduces moisture content (Themelis, 2002). This material is processed further for recyclable metals and can be stored until needed. 35,000 tons of recyclable metals are recovered annually from pre-combustion magnets and bottom ash processing (Covanta SEMASS, n.d.). Once it is incinerated, the ash is sent through another magnet to recover additional recyclable materials. The remaining waste is about 10% of the original volume and gets landfilled.

The plant produces 720 kWh of electricity per ton of municipal solid waste. One hundred kilowatt-hours/ton is used to operate the facility and the rest is sold the local utilities (Themelis, 2002), which powers over 75,000 homes (Covanta SEMASS, n.d.). Particulate, sulfur dioxide, hydrogen chloride, nitrogen oxides, carbon monoxide, dioxins, and heavy metal emissions are all well below EPA standards, the result of waste feed preparation, gas control systems, high combustion temperature and technology improvements (Themelis, 2002).

In 2014, Massachusetts enacted a waste ban that requires businesses or institutions disposing of more than one ton of food per week to donate edible food or compost. One of the expressed goals of the policy change was to divert food waste from incineration, despite the energy generation that facilities like SEMASS create. Food waste makes up over 25% of Massachusetts’ waste stream, and the Solid Waste

Master Plan has set a goal of diverting 35% of this waste by 2020 (MassDEP, 2017). Landfill tipping fees in Massachusetts are some of the highest in the nation (Berdick, 2014), and space is decreasing with no new landfills permitted for the future (Abel, 2012). Despite the benefits that SEMASS has shown, the state is interested in reducing its use by diverting food waste to aerobic or anaerobic digestion because of high landfill tipping fees and the possibility for a new, renewable energy source.

Composting: San Francisco

In 2009, San Francisco passed the Mandatory Recycling and Composting Ordinance that requires residents to separate recyclables, compostables, and trash (Cote, 2009). This was the first local ordinance that mandates separation of organics, and passed with strong support from the city board. Residents who do not properly sort have several warnings before facing a fine of $100. The intent of the ordinance was to cut two-thirds of the 618,000 tons of waste that the city landfilled in 2007. Opposition to the ordinance came from concerns of privacy and impacts of fines. To encourage the transition, the city provides recycling and compost bins for a much lower rate than trash bins, and additional savings to households come from switching to a smaller bins.

San Francisco sets rates for permits to service specific areas of the city that have all been purchased by a single company (EPA, n.d.). Recology, a private waste hauler, now services the entire city's municipal solid waste collection, and has a composting facility located in Vacaville, 60 miles from the city (Bialik, 2014). Their facility starts with a grinding stage to reduce the size of organic waste and then screens for trash. (Bialik, 2014) After a second grinding stage, the organic material is put in an open container and periodically turned and watered. This process takes several months, after which finished compost is amended with specific additives for customers' soil. Farmers can buy compost for $12 per cubic yard, and demand often exceeds the supply. The facility has had problems with improperly sorted compost that has non-compostable waste mixed in. Because source separation is the responsibility of San Francisco, this has become a bigger problem with the new waste stream. Removing problem waste like plastic bags is an additional cost, and anything missed damages the compost.

Despite a strict ordinance and city wide support, the city had an increase of almost 500,000 tons of landfilled waste in 2013 (Bialik, 2014). With this increase, it is unlikely the city will reach its goal of zero waste by 2020, regardless of the city wide support. It is uncertain what caused this increase but one suggestion from the city was the burgeoning tech industry (Bialik, 2014). This is a case where citizens were behind the mission, new bins and education was provided, and the strongest mandate was put in place, but residents are still trashing items that have another use. It could be the case that the popularity of the city, in part because of environmental initiatives like zero waste goals, could actually prevent attaining these goals.

Anaerobic Digestion: The East Bay Municipal Utility District

The East Bay Municipal Utility District (EBMUD), which serves the eastern side of the San Francisco Bay, has an anaerobic digester in their wastewater treatment plant and has studied the benefits and limitations of processing food waste from restaurants, grocery stores, and other facilities. The plant started this process in 2004, to supplement excess capacity in their digesters. This infrastructure was developed decades ago when Oakland was the largest food-processing center in the United States (Kerr, 2010). Some of this industry has since left and the wastewater treated had diminished by a third, leaving infrastructure under-used, while costs to run the plant have remained the same. The plant experimented with more efficient energy production after the California electricity crisis in 2000 and began adding waste from animal slaughterhouses, slowly transitioning to adding food scraps (Kerr, 2010). After realizing the improvements in energy production, the plants started to take on more waste, including post-consumer waste. The one addition to the plant was a food waste processing system to remove contaminants such as cutlery, plastic, and cloth (Hagey, 2011).

This is the first wastewater treatment facility to include food waste in their stream and the EPA awarded a grant to further study the benefits of this innovation. The volume of methane production increased three-fold from food waste, but is also more readily digestible and requires a short residence time (EPA, 2015). Before using food scraps, EBMUD produced 40-50% of its electricity through anaerobic digestion. After adding in food scraps, 90% of its electricity is produced. At times it is able to sell excess electricity to the power grid (Kerr, 2011). The income from waste hauled is about $8 million from the tipping fees to take the waste, and cost of electricity that is avoided saved $2.5 million a year (Day, 2012). In early 2012, a new turbine was added, and it is entirely energy sufficient, producing 15% more power than it uses. By 2020, EBMUD hopes to be selling twice as much electricity as it uses. The sales are accounting for $500,000 a year in revenue, but new long-term supply contracts would double that amount. The plant plans to add a digester solely for food that would allow for the sale of fertilizer or compost, which would also add to their revenue stream.

Context of Food Waste Management for Minnesota, Hennepin County, and Minneapolis

Waste management policy and planning is complicated because there are goals set at the state, regional, county, and local level that do not always align and private stakeholders within these realms (see Figure 7). At the state level, the Minnesota Pollution Control Agency (MPCA) sets goals for the Twin Cities Metropolitan Area with the Metropolitan Solid Waste Management Policy Plan that comes out every six years. The latest plan from MPCA for 2016-2036 stresses the importance of government involvement in waste management, but recognizes that goals are unachievable without working with private waste management companies (MPCA, 2017). The latest plan also emphasizes waste reduction, but also seeks to utilize the energy potential of waste and increase recoverable materials such as organics and recyclables (MPCA, 2017). MPCA set a goal in the 2010-2030 plan of 50% recycling recovery rate by 2015 which the metropolitan region was able to meet. The newest plan for 2016-2036 has a recycling recovery rate goal of 75% by 2030 and emphasizes the importance of organic recycling recovery required to meet this goal.

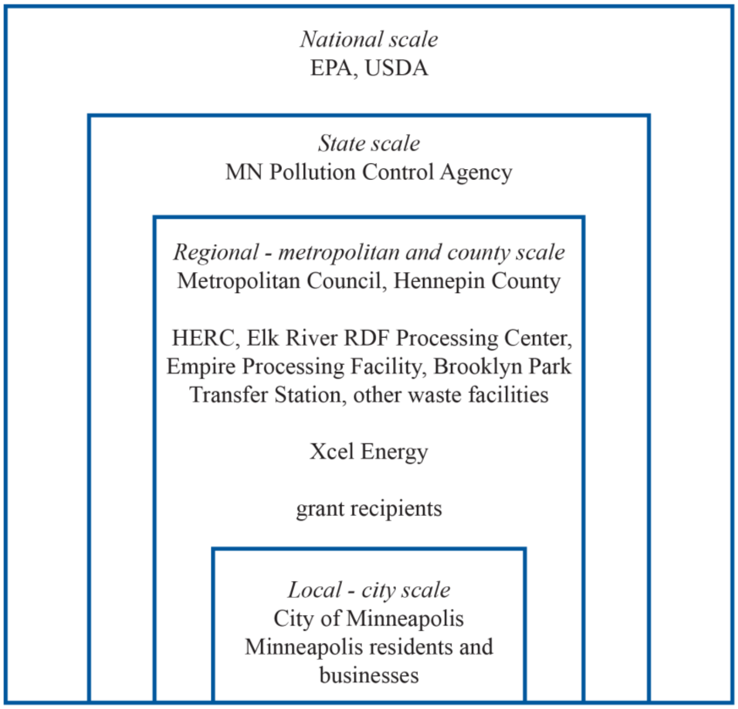

Figure 7. Specific stakeholders in food waste management for the city of Minneapolis

Existing capacity for organic recycling exceeds the current demand, but to meet the 2030 goal, new or expanded facilities will be required (MPCA, 2017). Currently there are nine facilities permitted to accept food waste in the state (MPCA, n.d). The state has made grant funding available and changed regulations that support expansion and development of composting facilities (MPCA, 2017). When it comes to technologies to support this goal, the state encourages further research on the benefits of anaerobic digestion. Questions remain on the effectiveness of anaerobic digestion, mostly over the usability of the digestate. The state wants a life cycle assessment of waste management technologies to inform policy by 2019.

Hennepin County is required by state statute to prepare a solid waste plan every six years, informed by the goals and policies of the Metropolitan Solid Waste Management Policy Plan. The county plan informed by the state's 2016-2030 plan will come out in 2018 and is currently seeking input from stakeholders (Hennepin County, n.d.). The 2012 plan stated the county's interest in composting and organic recovery, doubling the goal for organic recovery set by the state's 2010-2030 policy plan (Hennepin County, 2012). A lot of this was due to a public engagement process that revealed a strong interest in a residential organic recycling program. Development of curbside composting programs in Hennepin County cities has helped exceed the organic recovery rate goal.

At the time of the 2012 plan, the county provided grants and technical assistance to 120 schools, businesses, and 5,000 households to implement organic recycling programs (Hennepin County, 2012). They also distributed backyard compost bins to divert food waste from municipal solid waste. The county lowered the tipping fee for organic waste at the county's transfer station in Brooklyn Park, and residents and small businesses could use the facility for free. Finally, they have partnered with the University of Florida to assess the possibility of anaerobic digestion for food waste. Despite the interest in organic recycling and composting, the county requested an 11% capacity expansion of the Hennepin Energy Recovery Center, a WTE facility in the city of Minneapolis.

The city of Minneapolis does not have a formalized plan for waste management available but has documented the impacts of their waste through a greenhouse gas inventory that informs their Climate Action Plan. The Plan sets three goals that pertain to organic waste: a zero percent growth in waste streams from 2010 levels, recycle 50% of commercial and residential waste by 2025, and collection 15% of organic waste for composting by 2025 (City of Minneapolis, 2013). The plan also expresses interest in localizing organic processing facilities by updating zoning codes and licensing changes for smaller scale composting facilities. Curbside composting is currently only available for residential waste, despite the fact that more than half of organic waste is produced by the commercial sector (Roper, 2014). However, the emissions from transportation exceed saved emissions from diverting some residential food waste from other management facilities (Foth, 2013).

The city of Minneapolis has interest in becoming a zero waste city and has a zero-waste coordinator (Rao, 2014), but no formalized waste management plan is available. Policy that would support this goal, such as plastic bag bans, are often met with hostility from state representatives, who have countered local initiatives with legislation disallowing plastic bag bans (Golden, 2017). MPCA supports policy changes that encourage reducing and recycling waste, but opposition attempts from the legislature goes to show that the goals of waste reduction and recycling are not universal.

Minneapolis residential municipal solid waste is incinerated at the Hennepin Energy Recovery Center (HERC) (City of Minneapolis, 2012). 40% of commercial waste, which includes multi-family units, is incinerated at HERC; other waste is sent to Elk River Refuse-Derived Fuel Processing Facility and seven landfills outside of the city. Minneapolis and Hennepin County have two of the three discussed technologies available to them: WTE and composting. Despite availability of recycling and composting, landfilling of waste has been increasing for the Twin Cities since 2013 (Roper, 2017). This is a similar issue to the San Francisco case and may point to the problem of policies relying on citizen behavior. Despite more and more outlets for diverting waste from landfills and two outlets provided by the city to deter trash, the behavior is not reducing the use of landfills.

1. Hennepin Energy Recovery Center

Hennepin Energy Recovery Center (HERC), the WTE facility in downtown Minneapolis, began operation in 1989 (Hennepin County, 2011). The cost to build the facility was $160.5 million and operation costs on a yearly basis are around $30 million. Energy production creates revenues that offset most of these costs. State permits and local ordinances limited capacity to 365,000 tons of waste per year, though physical capacity is 405,000 tons. Screening processes before and after incineration recovers 11,000 tons of recyclable metal, and the remaining ash, 10% of original volume, is landfilled (Hennepin County, n.d.). The locations of these landfills are outside the boundaries of Hennepin County; one site is located in Wisconsin.

The generated heat and electricity is used in downtown Minneapolis' district energy system and powers 25,000 homes. The facility was purposefully sited near waste sources and markets that would buy the produced energy, such as Xcel Energy’s Aldrich substation, NRG Energy’s district energy system, and Target Field (Hennepin County, 2011). Waste incineration is considered a renewable energy source at the state and federal level; HERC is registered with the Midwest Renewable Energy Tracking System, which awards one renewable energy credit for each megawatt-hour of electricity produced. Since 1990, energy production from HERC was equivalent to 7 million barrels of oil or 2.8 million tons of coal.

The HERC facility is regulated by federal, state, and regional standards (Hennepin County, 2011). At the federal level, the facility holds a Title V air permit which is regulated by the Clean Air Act but issued by state or local agencies to major sources of air pollution; it is required of all municipal waste combustors (EPA, n.d.). The National Pollutant Discharge Elimination System permit is regulated by the Clean Water Act and limits what the facility can discharge (EPA, n.d.). The Minnesota Pollution Control Agency requires a Sanitary Sewer Modification Permit when modifications to a facility will affect the sanitary sewer system (MPCA, 2009). At the regional level, the facility must be reviewed and approved by Metropolitan Council Environmental Services (Hennepin County, 2011). Modifications such as facility expansion must also be approved at the city level (Hennepin County, 2012).

Emission reduction strategies from Maximum Achievable Control Technology standards are in place to control nitrogen oxide, mercury, sulfur dioxide and hydrochloric acid, particulate matter, metals, and dioxins (Hennepin County, 2011). In 2014, air emissions were on average 80% below permitted levels set by MPCA. While still below permitted levels, hydrogen chloride was 55% of the level and nitrogen oxide were 64% of the level. Management of ash is set by industry standards, Minnesota Pollution Control Agency and Wisconsin Department of Natural Resources (one landfill is in WI).

There is strong opposition in Minneapolis to the HERC facility. The Sierra Club, Neighborhoods Organizing for Change, and the Minnesota Public Interest Research Group have campaigned together to close the facility due to local pollution impacts (Tigue, 2016). Evidence has come from MPCA data showing violations of state standards for particulate matter and heavy metals in North Minneapolis

(MPCA, 2015). Particulate matter, lead, chromium, cobalt, and nickel are found in higher concentrations in the North Minneapolis neighborhoods adjacent to the facility (McMahon, 2015). These can contribute to respiratory illnesses, developmental issues in children, cardiovascular issues in adults, and higher rates of carcinogenic effects. These health problems have not been explicitly linked to emissions from HERC, but many see the facility as a contributor to health issues (McMahon, 2015). Because these health problem are predominately affecting neighborhoods with high concentrations of poverty and people of color, the HERC facility is viewed as an environmental justice issues for many people in Minneapolis (Tigue, 2016).

In 2009, Hennepin County attempted to increase the capacity of HERC by 11% (Olson, 2014). However, the city of Minneapolis was not willing to grant permission for this. This resulted in a five year conflict, ending in the Hennepin County Board voting down expansion. Arguments against the expansion emphasized the polluting effects of WTE sites and the potential for other uses of that waste, such as recycling and composting (Ellison, 2015). The result of this conflict was an increased interest from both the county and the city in composting (Olson, 2014).

2. Organic Recovery

Curbside composting of residential waste began in Minneapolis in 2015. Composting facilities in Minnesota that process this waste must obtain a Solid Waste permit from the MPCA. These permits place limits on odors, surface water runoff, and contaminants (MN Office of the Revisor of Statues, n.d.). Currently eight cities in the county offer curbside composting services to all residents (Hennepin County, n.d). Fourteen cities do not have full coverage and only have services through specific haulers. An increase in organic recycling will require an increase in capacity (Hennepin County, 2012). To accommodate the increase in organic waste, the current composting facilities have used static pile composting which has caused odor problems. With the growing capacity, better facilities that utilize aeration will need to be developed. In the long run, the county is interested in developing new technologies that manage organics, such as anaerobic digestion.

Despite the development of curbside composting in a number of Hennepin County cities, a recent study found 24.9% of waste at the HERC was organics and food waste (Hennepin County, 2016). Removing food waste from this stream would make the HERC and Elk River facilities that serve Minneapolis more effective but would also reduce capacity, which would likely be popular within the city. However the removed waste has to have an outlet. Currently, composting is being used at the city and county level, but there is only one facility located in Dakota County that is accepting organic waste (City of Minneapolis, n.d.).

Policy Implications

The governance of food waste is complicated by the recommendations and goals of various scales of government and the presence of private and public waste haulers and facilities. While it is important to consider the costs and benefits to each of these scales, decision making is mostly taking place at the city and county level. This raises questions over who should be setting food waste goals, who has the capacity to help reach them, and what should be done when goals conflict. Finally, while goal setting is important in guiding policy making, what goals are leading to outcomes that actually reduce the global, regional, and local impacts of food waste?

The combination of technology comparison, stakeholder views, and case studies help form recommendations for the city of Minneapolis (Table 2). All three considerations support the diversion of waste from landfilling. More specifically, there is also a strong case to divert food waste from WTE facilities. WTE is promoted at the federal and state level through renewable energy subsidies, which could provide a disincentive to phase these technologies out. However, strong public opposition and the backing of the city of Minneapolis was able to stop the HERC facility from expanding, so local support can have a strong impact on technology choices. Furthermore, when it comes to food waste, WTE is poor at dealing with organic material, stakeholders at national, state, and local levels list it as the least preferable technology, and the commercial food waste ban in Massachusetts despite a renowned WTE facility support other technology options such as composting or anaerobic digestion.

Table 2. Tradeoffs at Various Spatial Scale of Waste Technology Options for Minneapolis

Scale	Landfilling	Waste-to-energy *HERC*	Composting *Empire Processing Facility*	Anaerobic Digestion
Local	Has the lowest levels of support from community and city Least effective at dealing with food waste	Low levels of community and city support More effective with food waste than landfilling, but efficiency is reduced with inclusion of food waste Energy generation utilized by downtown Minneapolis district heating system and electricity use	High level of community and city support in development of curbside composting program	Interest in technology from community and city Most effective at dealing with food waste Could be a source for renewable energy generation
Regional	Landfills for Minneapolis are all located outside of the city and Hennepin County are privately owned Experiences impacts from pollution Landfills used by city do not all use landfill gas capture	Ash brought to landfill in Minnesota and Wisconsin Saved 8 million cubic yards of landfill space and use of 2.8 million tons of coal since 1990 (Hennepin County, 2011) Considered a renewable energy source	Compost available for residents, agriculture, and commercial sector No energy generation Increase efficiency of HERC with food waste diversion	Not fully endorsed by Hennepin County and state of Minnesota with a preference for composting food waste Energy production could be utilized as a renewable source Digestate could produce compost for agricultural purposes
Global	Highest carbon footprint	Medium	Medium	Lowest carbon footprint and has biggest impact on climate change mitigation

Minneapolis has recently added curbside composting for residential food waste. This seems to have developed from two factors: state recommendations and local public opposition to HERC. The Minnesota Pollution Control Agency recommends diverting food waste from incinerations but also promotes composting over industrial use. The HERC facility is negatively impacted by processing food waste but is also unpopular enough in Minneapolis that the expansion of the HERC facility was denied. The combination of state and regional support for other food waste outlets and negative public perception of WTE shifted the focus of both the city and the county to expanding curbside composting programs. While Massachusetts did not have strong opposition to their WTE facility, they too took the initiative to divert food waste, in large part due to high landfill rates.

Minnesota stakeholders support composting over anaerobic digestion as solutions for food waste, despite the regional and global benefits of anaerobic digestion and the success of the EBMUD support further the case for this technology. Additionally, Minneapolis and San Francisco have both experienced increased landfilling despite composting program development that could support use of a different food waste management strategy. The EBMUD case study shows that anaerobic digestion technology could already exist and be a useful place to experiment. However, Minneapolis wastewater treatment facilities may not have as much capacity as Oakland. Regardless the success of including food in their waste stream support experimentation.

Minneapolis has informally set a zero waste goal, a much more rigorous standard than that of the county and state. The city does not have the strictest accompanying policy of a food waste ban, but does divert residential waste from HERC with the program. Measurements of waste have only been reported at the county level, which makes it hard to assess whether composting has improved waste management in the city itself. However, with the county as a whole experiencing higher rates of landfilling, the implications of this are that food waste bans or diversions are not the only solution to reducing landfilling. As the region continues to grow, there is no reason to expect this trend would not continue without better management strategies. Furthermore, zero waste goals have to address more than just food waste.

As organic collection continues to grow in Minneapolis and Hennepin County, expansion of composting or anaerobic digestion facilities will likely be need. The city has promoted composting and there is talk of distributed composting infrastructure throughout the city. However these facilities often face similar opposition as WTE; no one wants to live near them. When they are sited well outside of the city, the benefits of waste diversion are reduced. If new facilities need to be built, the benefits of energy production and reduced carbon footprint may make anaerobic digestion the better option, even though this technology is not promoted by the state. Further, the city has proved it can be a powerful force for change in waste management as seen from the failed HERC expansion attempt. The city could be a voice for development of more innovative technologies for food waste despite significant levels of funding coming from the county and state level.

Ultimately, cities do not exist in a vacuum. While they are able to set innovative goals, they need the support of larger government agencies and private industry to help meet waste goals. Focusing on food waste acknowledges that different streams of waste can be utilized for different purposes, but each stream requires additional facilities and technologies. Further, the benefits of WTE, composting, and anaerobic digestion are highly dependent on inputs, sophistication of the technology, and use of the byproduct. When deciding on appropriate waste management strategies, it is important to consider the support system from the government and the capability to develop impactful technology, as these have been shown to help foster more successful, though not perfect, food waste interventions.

References

1. Albina, D. and Themelis, N. (2003). Emissions from Waste-to-Energy: A comparison with coal-fired Power Plants. *ASME International Mechanical Engineering congress and Exposition.* Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.541.732&rep=rep1&type=pdf
2. American Biogas Council. What is Anaerobic Digestion? *ABC*. Retrieved from https://www.americanbiogascouncil.org/biogas_what.asp
3. Baptista, A. and Amarnath, K. (2016). Garbage, Power, and Environmental Justice: The Clean Power Plan Rule. *The New School.* Retrieved from http://blogs.newschool.edu/tedc/files/2016/07/Baptista_Garbage_Power_CPP1.pdf
4. Barclay, E. (Oct. 8, 2011). How That Food You Throw Out Is Linked To Global Warming. *NPR*. Retrieved from http://www.npr.org/sections/thesalt/2011/10/07/141123243/how-that-food-you-throw-out-is-linked-to-global-warming
5. Bialik, C. (2014). San Francisco Stalls In Its Attempt To Go Trash-Free. *FiveThirtyEight*. Retrieved from https://fivethirtyeight.com/features/san-francisco-stalls-in-its-attempt-to-go-trash-free/
6. Breitenbeck, G. and Schellinger, D. (2004). Calculating the Reduction in Material Mass And Volume During Composting. *Compost Science and Utilization, 12:4.* 365-371.
7. Britz, W. and Delzeit, R. (2013). The impact of German biogas production on European and global agricultural markets, land use and the environment. *Energy Policy, 62*. 1268-1275.
8. Bryen ,W. (2015). Lafayette residents split over curbside composting. *Daily Camera.* Retrieved from http://www.dailycamera.com/lafayette-news/ci_27607145/lafayette-residents-split-over-curbside-composting
9. CalRecycle. (June, 18, 2013). Composting and Anaerobic Digestion. Retrieved from http://www.calrecycle.ca.gov/Actions/Documents%5C77%5C20132013%5C900%5CCompostin%20and%20Anaerobic%20Digestion.pdf
10. Cave, S. (Feb. 18, 2013). Anaerobic Digestion across the UK and Europe. *Northern Ireland Assembly*. Retrieved from http://www.niassembly.gov.uk/globalassets/documents/raise/publications/2013/environment/5213.pdf
11. Center for Ecotechnology. (Oct. 6, 2015). After One Year, Mass. Commercial Food Waste Disposal Ban Gets Results. *Center for Ecotechnology*. Retrieved from http://www.cetonline.org/after-one-year-mass-commercial-food-waste-disposal-ban-gets-results/
12. Cheeseman, G. (Aug. 12, 2014). Massachusetts Food Waste Ban Goes Into Effect in October. *Triple Pundit.* Retrieved from http://www.triplepundit.com/2014/08/massachusetts-food-waste-ban-goes-effect-october/
13. Chatterjee, et al. (2013). Chemical and Physical Characteristics of Compost Leachates: A Review. *Prepared for the Washington State Department of Transportation.* Retrieved from https://www.wsdot.wa.gov/research/reports/fullreports/819.1.pdf
14. City of Minneapolis. (2012). Greenhouse Gas Inventories: A Geographic Inventory (2006-2010) and Household Consumption-based Inventory (2010). *City of Minneapolis.* Retrieved from

http://www.minneapolismn.gov/www/groups/public/@citycoordinator/documents/webcontent/wcms1p-092812.pdf

15. Covanta (2016). Excellence Award Entry, Waste-to-energy Category, SEMSS Reousrce Recovery Facility. Retrieved from https://swana.org/Portals/0/awards/2016/winners/SEMASSResourceRecoveryFacility_WasteToEnergy.pdf
16. Cuellar, A. and Webber, M. (2010). Wasted Food, Wasted Energy: The Embedded Energy in Food Waste in the United States. *Environmental Science and Technology, 44, 6464-6469.*
17. Day, D. (Dec 2012). Beyond Net Zero. *Treatment Plant Operator Magazine*. Retrieved from http://www.tpomag.com/editorial/2012/12/beyond_net_zero.
18. De Baere, L. and Mattheeuws, B. (2015). Anaerobic Digestion of the Organic Fraction of Municipal Solid Waste in Europe. *Waste Management, Vol. 3. 517-526.*
19. EIA (n.d.) Waste-to-Energy (Municipal Solid Waste). *US Energy Information Administration*. Retrieved from https://www.eia.gov/energyexplained/index.cfm/data/index.cfm?page=biomass_waste_to_energy
20. EIA (2007). Methodology for Allocating Municipal Solid Waste to Biogenic and Non-Biogenic Energy. *Energy Information Administration.* Retrieved from https://www.eia.gov/totalenergy/data/monthly/pdf/historical/municipal solid waste.pdf
21. EPA. (n.d.). Operating Permits Issued under title V of the Clean Air Act. Retrieved from https://www.epa.gov/title-v-operating-permits
22. EPA. (n.d.). National Pollutatn Discharge elimination System. Retrieved from https://www.epa.gov/npdes/npdes-permit-basics
23. EPA. (n.d.). Air Emissions from MUNICIPAL SOLID WASTE Combustion Facilities. *EPA.* Retrieved from https://archive.epa.gov/epawaste/nonhaz/municipal/web/html/airem.html
24. EPA. (n.d.) Food Recovery Hierarchy. *Sustainable Management of Food*. Retrieved from https://www.epa.gov/sustainable-management-food/food-recovery-hierarchy
25. EPA. (n.d.) Guidelines and Permitting for Livestock Anaerobic Digesters. Retrieved from https://www.epa.gov/agstar/guidelines-and-permitting-livestock-anaerobic-digesters#permitting
26. EPA (n.d.) Zero Waste Case Study: San Francisco, CA. Retrieved from https://www.epa.gov/transforming-waste-tool/zero-waste-case-study-san-francisco-ca
27. EPA (2014). Economic Impact Analysis for the Proposed New Subpart to the New Source Performance Standards. *EPA.* Retrieved from https://www3.epa.gov/ttnecas1/regdata/EIAs/LandfillsNSPSProposalEIA.pdf
28. Ellison, K. (2015). Why get trashed when you can recycle? *MinnPost*. Retrieved from https://www.minnpost.com/community-voices/2015/09/why-get-trashed-when-you-can-recycle
29. Environmental Protection Agency (Oct. 14, 2015). Turning Food Waste into Energy at the East Bay Municipal Utility District. *EPA.* Retrieved from http://www3.epa.gov/region9/waste/features/foodtoenergy/
30. FAO. (2011). Global food losses and food waste – Extent, causes and prevention. Rome. Retrieved from http://www.fao.org/docrep/014/mb060e/mb060e.pdf
31. FAO. (2013). Food wasteage footprint: Impacts on natural resources. *FAO.* Retrieved from http://www.fao.org/docrep/018/i3347e/i3347e.pdf
32. Foth Infrastructure & Environment (2013). Assessment of Residential Source Separated Organics Collection Options. A Study for the City of Minneapolis. Retrieved from

http://www.ci.minneapolis.mn.us/www/groups/public/@publicworks/documents/webcontent/wcms1p-121817.pdf

33. Foth Infrastructure & Environment, LCC, et al. (2016). 2016 Minneapolis Residential Solid Waste Composition Analysis And Recycling Program Evaluation: Final Report. *Foth Infrastructure & Environment, LCC.* Retrieved from http://www.hennepin.us/-/media/hennepinus/your-government/projects-initiatives/documents/hennepin-county-waste-sort-study-2016.pdf?la=en
34. Fischer, J. (Nov. 2015). Massachusetts Commercial Food Scraps Disposal Ban: One-Year Milestone. *MassDEP*. Retrieved from http://www.epa.gov/sites/production/files/2015-11/documents/fischer.pdf
35. Funk, K., Milford, J., and Simpkins, T. (2013). Analyzing the Economic and Environmental Viability of Waste-to-Energy (WTE) Technology for Site-Specific Optimization of Renewable Energy Options. *National Renewable Energy Laboratory*, Technical Report. Retrieved from http://www.nrel.gov/docs/fy13osti/52829.pdf
36. Geiling, N. (Sept. 17,2015). The U.S. Government Wants To Cut Food Waste In Half. *Climate Progress.* Retrieved from http://thinkprogress.org/climate/2015/09/17/3702620/usda-epa-food-waste- goals/
37. Giusti, L. (2009). A review of waste management practices and their impact on human health. *Waste Management, 29:8,* 2227-2239.
38. Gunders, D. (2012). Wasted: How American Is Losing Up to 40 Percent of Its Food from Farm to Fork to Landfill. *NRDC.* Retrieved from https://www.nrdc.org/sites/default/files/wasted-food-IP.pdf
39. Hagey, P. (Nov. 2011). Utility District Ramps Up Food Waste-to-energy Program. *BioCycle*. Retrieved from http://www.biocycle.net/2011/11/18/utility-district-ramps-up-food-waste-to-energy- program/
40. Hanson, C. et al. (2015). What's Food Loss and Waste Got to Do with Climate Change? A Lot, Actually. *World Resource Institute.* Retrieved from http://www.wri.org/blog/2015/12/whats-food-loss-and-waste-got-do-climate-change-lot-actually
41. Hargreaves, J.C., Adl, M.C., and Warman, P.R. (2008). A review of the use of composted municipal solid waste in agriculture. *Agriculture, Ecosystems and Environment, 123.* 1-14.
42. Hartmann, H. and Ahring, B.K. (2006). Strategies for the anaerobic digestion of the organic fraction of municipal solid waste: an overview. *Water Science and Technology, 53:8*, 7-22.
43. Hendricks, M. (Jan. 2014). More states ban organic waste in landfills. *American Recycler News, Inc.* Retrieved from http://www.americanrecycler.com/0114/2428more.shtml.
44. Hennepin County. (n.d.). Solid waste planning. Retrieved from http://www.hennepin.us/solidwasteplanning
45. Hennepin County. (n.d.) Hennepin County Energy Recovery Center. Retrieved from http://www.hennepin.us/-/media/hennepinus/your-government/facilities/documents/herc-factsheet.pdf
46. Hennepin County. (n.d.). Organics recycling for residents. Retrieved from http://www.hennepin.us/residents/recycling-hazardous-waste/organics-recycling
47. Hennepin County. (2011). Hennepin Energy Recovery Center: An urban waste-to-energy facility. *SWANA 2011 Waste-to-Energy Excellence Award Application.* Retrieved from https://swana.org/Portals/0/Awards/2011Noms/Wasto_To_Energy_Gold.pdf

48. Hennepin County. (2012). Hennepin County Solid Waste Management Master Plan. *Hennepin County Environmental Services.* Retrieved from http://www.hennepin.us/~/media/hennepinus/your-government/projects-initiatives/documents/solid-waste-version-9.pdf?la=en
49. Hennepin County (2016). Sorting out our waste problem. *Hennepin County*. Retrieved from http://www.hennepin.us/-/media/hennepinus/your-government/projects-initiatives/documents/waste-sort-executive-summary.pdf?la=en
50. Jaffe, J. and Mattes, M. (Nov. 27, 2013). Biomethane Rising: California Policies Open the Gate to Electricity and Natural Gas Markets. *Fortnightly's Spark*. Retrieved from http://www.nossaman.com/BiomethaneRising
51. Jeswani, H., Smith, R., and Azapagic, A. (2012). Energy from waste: corbon footprint of incineration and landfill biogas in the UK. *International Journal of Life Cycle Assessment. 18:1.* 218-229.
52. Jossi, F. (2016). In Minnesota, waste-to-energy debate firing up once again. *Midwestern Energy News.* Retrieved from http://midwestenergynews.com/2016/04/26/in-minnesota-waste-to-energy-debate-firing-up-once-again/
53. Kerr, D. (Nov. 10, 2010). EBMUD turns food scraps into electricity. *Oakland North*. Retrieved from https://oaklandnorth.net/2010/11/10/ebmud-turns-food-scraps-into-electricity/
54. Klinkner, B. (2014). Anaerobic Digestion as a Renewable Energy Source and Waste Management Technology: What Must be Done for This Technology to Realize Success in the United States. *UMass Law Review, 9, 68,* 68-96.
55. Kraemer, T. and Gamble, S. (2014). Integrating Anaerobic Digestion With Composting. *BioCycle. 55: 10.* 32.
56. Kubler, H., Rumphorst, M. (1999). Evaluation of process for treatment ☐of biowaste under the aspects of energy balance and CO2 emission. Proceedings of the Second International Symposium on Anaerobic Digestion of Solid Wastes, Barcelona, vol. 1, 92, pp. 405-410.
57. Kuo, J. (2015). Air quality issues related to using biogas from anaerobic digestion of food waste. Retrieved from https://www.cmsa.us/assets/documents/Studies%20&%20Projects/Final%20Biogas%20Study%20-%20Feb%202015.pdf
58. Layzer, J. and Schulman, A. (2014). Municipal Curbside Compostables Collection: What Works and Why? *Urban Sustainability Assessment Project, Department of Urban Studies and Planning, MIT.* Retrieved from https://dusp.mit.edu/sites/dusp.mit.edu/files/attachments/project/Municipal%20Curbside%20Compostables%20Collection%20%20What%20Works%20and%20Why.pdf
59. Leschin-Hoar, C. (Sept. 9, 2014). Banning food waste: companies in Massachusetts get ready to compost. *The Guardian.* Retrieved from http://www.theguardian.com/sustainable-business/2014/sep/09/food-waste-ban-massachusetts-compost-landfill-food-banks
60. Levis, J. and Barlaz, M. (2011). What Is the Most Environmentally Beneficial Way to Treat Commercial Food Waste? *Environmental Science and Technology, 45,* 7438-7444.
61. Lott, M. (Sept. 2013). UN says that if food waste was a country, it'd be the #3 global greenhouse gas emitter. *Scientific American Blog*. Retrieved from http://blogs.scientificamerican.com/plugged- in/un-says-that-if-food-waste-was-a-country-ite28099d-be-the-3-global-greenhouse-gas-emitter/

62. Lou, X. F. and Nair, J. (2009). The impact of landfilling and composting on greenhouse gas emissions – A review. *Bioresource Technology. 100,* 3792-3798.
63. MAPC. (2014). Develop Anaerobic Digestion/Combined Heat& Power. Retrieved from http://www.mapc.org/system/files/bids/Develop%20Anaerobic%20Digestion.pdf
64. Mata-Alvarez, J. (Aug. 2000). Anaerobic Digestion of Organic Solid Wastes. An Overview of Research Achievements and Perspectives. *Bioresource Technology, 74, 3-16.*
65. McMahon, C. (2015). North Minneapolis Air Monitoring Study: 2015 Data Summary. *Minnesota Pollution Control Agency.*
66. Minnesota Pollution Control Agency. (2009). Sanitary Sewer Modifications, Additions or Extension Permits. When are Permits Required? Retrieved from https://www.pca.state.mn.us/sites/default/files/wq-wwprm1-15.pdf
67. Minnesota Pollution Control Agency. (2013). 2013 Statewide Waste Characterization Final Report. *Burns & McDonnell Engineering Company, Inc.* Retrieved from https://www.pca.state.mn.us/sites/default/files/w-sw1-60.pdf
68. Minnesota Pollution Control Agency. (2016). 2015 Solid Waste Policy Report. *MN PCA.* Retrieved from https://www.pca.state.mn.us/sites/default/files/lrw-sw-1sy15.pdf
69. Minnesota Pollution Control Agency. (2017). Metropolitan Solid Waste Policy Plan 2016-2036. *MN PCA.* Retrieved from https://www.pca.state.mn.us/sites/default/files/w-sw7-21.pdf
70. Minnesota Pollution Control Agency. (n.d.). Compost facilities. Retrieved from https://www.pca.state.mn.us/waste/compost-facilities
71. Miranda, M. and Hale, B. (1997). Waste not, want not: the private and social costs of waste-to-energy production. *Energy Policy, 25: 6,* 587-600.
72. Moriarty, K. (Jan. 2013). Feasibility Study of Anaerobic Digestion of Food Waste in St. Bernard, Louisiana. *National Renewable Energy Laboratory.* Retrieved from http://www.nrel.gov/docs/fy13osti/57082.pdf.
73. Morris, J. (2010). Bury or Burn North America MUNICIPAL SOLID WASTE? LCAs Provide Answers for Climate Impacts & Carbon Neutral Power Potential. *Environmental Science and Technology. 44.* 7944-7949.
74. Office of the Revisor of Statutes. (n.d.). *Minnesota Administrative Rules.* Retrieved from https://www.revisor.mn.gov/rules/?id=7035.2836
75. Olson, R. (2014). Hennepin County drops trash-burning request, pushes Minneapolis on composting. *Star Tribune.* Retrieved from http://www.startribune.com/hennepin-county-drops-trash-burning-bid-pushes-minneapolis-on-recycling/243610431/
76. Platt, B. et al. (2014). State of Composting in the US. *Institute for Local Self-Reliance.* Retrieved from http://ilsr.org/wp-content/uploads/2014/07/state-of-composting-in-us.pdf
77. Pulido, L. (2000). Rethinking Environmental Racism: White Privilege and Urban Development in Southern California. *Annuals of the Association of American Geographers, 90:1,* 12-40.
78. Psomopoulos, CS., Bourka, A., and Themelis, NJ. (2009). Waste-to-energy: A review of the status and benefits in USA. *Waste Management, 29:5,* 1718-1724.
79. Pyper, J. (2011). Does Burning Garbage to Produce Electricity Make Sense? *Scientific American.* Retrieved from https://www.scientificamerican.com/article/does-burning-garbage-to-produce-energy-make-sense/
80. Roder, M. (2016). More than food or fuel. Stakeholder perceptions of anaerobic digestion and land use; a case study from the United Kingdom. *Energy Policy. 97,* 73-81.

81. Royte, E. (Oct. 13, 2014). One-Third of Food is Lost or Wasted: What Can Be Done. *National Geographic*. Retrieved from http://news.nationalgeographic.com/news/2014/10/141013-food-waste-national-security-environment-science-ngfood/
82. Sharma, R., et. al. (2013). The impact of incinerators on human health and environment. *Environmental Health*. Vol. 28, 67-72.
83. Simmons, C. (Jan. 21, 2014). California Issues Regulations to Implement Assemblyman Gatto's Landmark Green-Energy Bill. *California Newswire.* Retrieved from http://californianewswire.com/ california-issues-regulations-implement-assemblyman-gattos-landmark-green-energy-bill/
84. St. Clair, C. (2015). EPA and USDA Join Private Sector, Charitable Organizations to Set Nations First Goals to Reduce Wasted Food. *EPA.* Retrieved from https://www.epa.gov/newsreleases/epa-and-usda-join-private-sector-charitable-organizations-set-nations-first-goals
85. Themelis, N. and Reshadi, S. (2009). Potential for reducing the capital costs of WTE facilities. *17th Annual North American Waste-to-Energy Conference.* NAWTEC17.
86. Tigue, K. (2016). Environmental and community groups join forces to take on an old foe: the HERC. *Minnpost.* Retrieved from https://www.minnpost.com/community-sketchbook/2016/04/environmental-and-community-groups-join-forces-take-old-foe-herc
87. UNEP. (2010). Waste and Climate Change: Global trends and strategy framework. *UNEP*. Retrieved from http://www.unep.or.jp/ietc/Publications/spc/Waste&ClimateChange/Waste&ClimateChange.pdf
88. United States Department of Agriculture. (Sept. 16, 2015). USDA and EPA Join with Private Sector, Charitable Organizations to Set Nation's First Food Waste Reduction Goals. *Office of Communications* Retrieved from http://www.usda.gov/wps/portal/usda/usdamediafb?contentid=2015/09/ 0257.xml&printable=true&contentidonly=true
89. Van Haaren, R. (2009). Large scale aerobic composting of source-separated organic wastes: A comparative study of environmental impacts, costs, and contextual effects. *Columbia University*. Retrieved from http://www.seas.columbia.edu/earth/wtert/sofos/haaren_thesis.pdf
90. Zakaria, J. & Sutin, G. (1994). The SEMASS Shred-and-Burn Technology: A Well Proven Resource System. *National Waste Processing Conference, 16,* 293-293.
91. Zhang, Q., Hu, J. and Lee, Duu-Jong. (2016). Biogas from anaerobic digestion processes: Research updates. *Renewable Energy*. *98,* 108-119.
92. Zhuang, Y. et al. (2008). Source separation of household waste: A case study in China. *Waste Management, 28,* 2022-2030.