Municipal Development of Anaerobic Digestion/ Combined Heat and Power in Massachusetts

A thesis submitted by

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ABSTRACT

With a commercial food waste ban going into effect in Massachusetts in October 2014, businesses, institutions, and municipalities are considering alternatives to landfills and incinerators for organic waste. Anaerobic digestion is one such alternative. Similar to composting, but in an environment devoid of oxygen, anaerobic digestion produces byproducts such as methane (which can be burned for heat or electricity) and liquid or solid digestate (which can be used as fertilizer, cattle bedding, and more). Thus, disposal of food waste and other organic materials can become a source of revenue rather than just an expense. Municipalities interested in developing anaerobic digestion/combined heat and power (AD/CHP) facilities have the benefit of desirable options for sites, such as landfill gas facilities and wastewater treatment plants, and potential feedstocks in source-separated residential or municipal food waste or wastewater. This thesis examines the opportunities and challenges for municipal development of AD/CHP facilities in Massachusetts.

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ABBREVIATIONS

AD – anaerobic digestion

ARRA – American Recovery and Reinvestment Act

CHP – combined heat and power

DOER – Department of Energy Resources

FOG – fats, oils, and grease

ISO-NE – Independent Systems Operator of New England

kWh – kilowatt hour

LLC – limited liability company

MassCEC – Massachusetts Clean Energy Center

MassDEP – Massachusetts Department of Environmental Protection

MGD – million gallons per day

MMBtu – million British thermal units

mmscfd – million standard cubic feet per day

MWh – megawatt hour

MWRA – Massachusetts Water Resources Authority

PILOT – payment in lieu of taxes

PPA – power purchase agreement

PV – photovoltaic

REC – renewable energy credit

SSO – source-separated organics

WMECO – Western Massachusetts Electric Company

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CHAPTER ONE: INTRODUCTION

In order to meet its goal of decreasing food waste sent to landfills or incinerators by a total of one million tons per year by 2020, the Commonwealth of Massachusetts is enacting a commercial food waste ban in October 2014. The ban will require entities that discard at least one ton of organic material per week to find alternative ways to dispose of it, and codigesting it with other feedstocks in anaerobic digesters is a promising method.

Anaerobic digestion is the process of breaking down organic waste through the use of bacteria in an environment without oxygen. It is similar to composting; however, with anaerobic digestion the material is contained within an air-tight vessel and the time required is lessened. The products of anaerobic digestion are biogas, digestate, and water. The biogas mostly consists of methane and carbon dioxide, with some hydrogen, hydrogen sulfide, and nitrogen. Biogas is an alternative energy source that stores well and is highly efficient at converting embodied energy into usable energy. Digestate is a solid or sludge that can often be used as fertilizer, soil conditioner, cattle bedding, or even fuel.

The biogas produced by anaerobic digestion can be burned onsite to heat anaerobic digestion tanks, dewater sludge, or heat the entire facility. With the use of an engine or turbine, biogas can also be used to generate electricity (referred to as combined heat and power or cogeneration) or be further purified into natural gas, compressed natural gas (CNG), or liquefied natural gas (LNG). Many existing AD facilities currently flare (burn) their methane rather than generate electricity.

Since many municipalities operate their own wastewater treatment plants, such plants represent a significant opportunity to begin development of AD/CHP facilities. However, of the 133 wastewater treatment plants in Massachusetts, only six have anaerobic digesters, and only three of those use the biogas to generate electricity. Landfills are also potential locations for AD/CHP facilities, especially if they already use landfill gas to generate electricity. However, while multiple landfill sites are being considered for AD/CHP, none have yet reached the construction phase. There is clearly much opportunity for growth.

The goal of this thesis is to examine the opportunities and challenges for municipal development of anaerobic digestion/combined heat and power facilities in Massachusetts. It seeks to answer the following questions:

- What are benefits and barriers to the development of AD/CHP?
- What is the current state of AD/CHP in MA?
- What forms of AD/CHP should be promoted and why?
- How can municipalities encourage development of AD/CHP?

METHODOLOGY

Initial data collection consisted of reviewing white papers, scholarly articles, and newspaper articles on the subject, first focusing on Massachusetts and then expanding to consider AD/CHP nation- and worldwide. In order to get the most up-to-date and detailed information possible, relevant officials were interviewed (see Appendix A). These included officials from Massachusetts state agencies that are involved in AD/CHP development, such as the Department of Environmental Protection and Massachusetts Clean Energy Center; regional AD/CHP facilities, such as the Deer Island Wastewater Treatment Plant; municipal AD/CHP facilities, such as Pittsfield and Fairhaven; municipalities considering AD/CHP facilities, such as Hamilton; and municipalities that have rejected AD/CHP, such as Lexington. The literature review was used to help develop the interview questions.

Case studies were developed for the Deer Island, Pittsfield, Fairhaven, Rockland, and Clinton wastewater treatment plants, because they represent multiple sizes of wastewater plants with anaerobic digestion, from the largest regional facility, Deer Island, to the smallest municipal facilty, Rockland. Case studies were also developed for the potential landfill sites of Hamilton and Lexington, the former because of its relatively successful process so far, and the latter because it was derailed by negative public reaction. A case study for Barstow's Longview Farm is also included to showcase an alternative to municipal facilites. Data sources for the case studies included information published by MassDEP and industry journals, as well as interviews with representatives from the facilities and tours of the facilities.

A component of this thesis was a GIS project analyzing potential locations for AD/CHP facilities in Massachusetts, based on their distance from available feedstocks, as well as other siting issues, such as public impact. It identified which sites may be more desirable from a large-scale perspective. In depth analysis of each site, including a feasibility study, would be required to confirm its suitability.

TECHNICAL BACKGROUND

ANAEROBIC DIGESTION/COMBINED HEAT AND POWER

Much like composting (aerobic digestion), anaerobic digestion uses bacteria to break down organic materials. However, unlike composting, it does so in an environment without oxygen, and the process takes place at an accelerated rate, less than a month. The result of this process is biogas, digestate, and water.

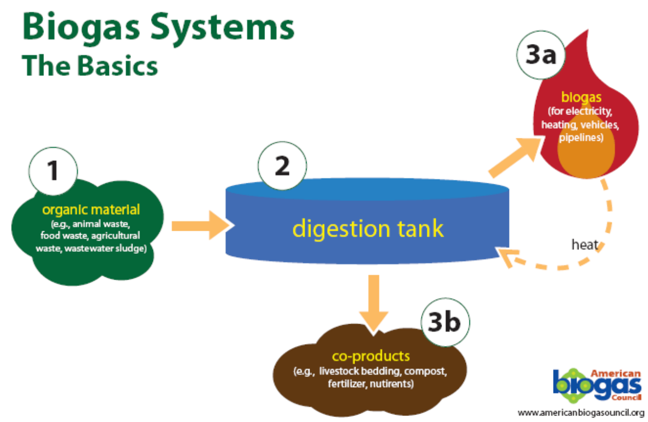

Figure 1: Biogas Basics (American Biogas Council, What Is Anaerobic Digestion?)

Anaerobic digestion is a four-stage process, sometimes all occurring within one container, sometimes in separate containers, with different bacteria instrumental to each stage. First, hydrolysis breaks down carbohydrates into sugars and amino acids. Then acidogenesis converts sugars and amino acids into organic acids, carbon dioxide, hydrogen, and ammonia. Next, acetogenesis converts organic acids into acetic acid, as well as carbon dioxide, hydrogen, and ammonia. Finally, methanogenesis converts these products into methane and carbon dioxide (American Biogas Council, What Is Anaerobic Digestion?; Appels, 2008).

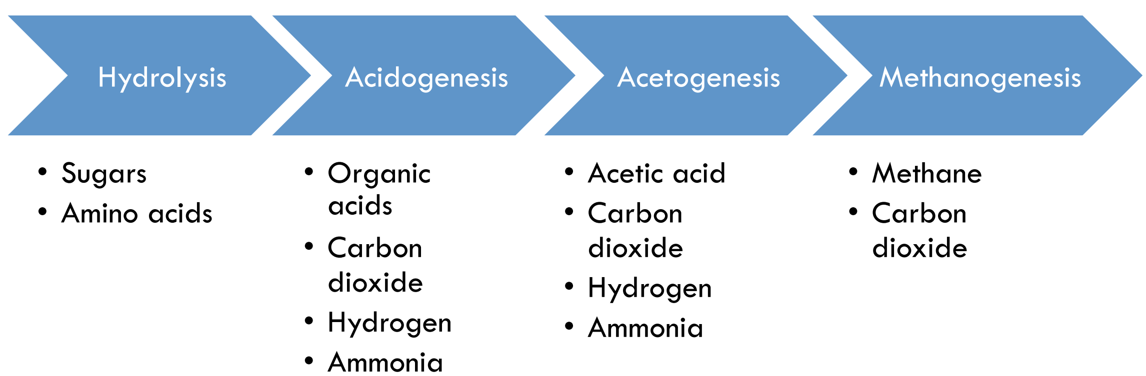

Figure 2: Anaerobic Digestion Process (Appels, 2008)

The bacteria are sensitive to many factors. Each group of bacteria has a different optimum pH range: for methanogenic bacteria it is 6.5 to 7.2 and for fermentative bacteria it is between 4 and 8.5. Volatile fatty acids tend to reduce the pH and methanogenesis tends to increase it. Temperature changes can also negatively impact the bacteria. Failure can occur with a temperature change of just 1 degree C per day. High temperatures increase the amount of ammonia. Bacteria can also be affected by concentrations of hydrogen, sulfide, sodium, potassium, heavy metals, and long-chain fatty acids. Because of this, alkalinity, volatile fatty acids, and biogas flow rate and composition should all be closely monitored (Appels, 2008).

The resulting biogas is made up mostly of methane (55-75%) and carbon dioxide (24-44%), with some other gases (1%) (American Biogas Council, Frequent Questions). Anaerobic digestion can process materials in about a month, and reduce the volume of material by up to 85%. The resulting digestate can have multiple uses, including as fertilizer, soil amendment, or pelletized fuel. The water that is separated from it will often be further treated by a wastewater utility before being released (Massachusetts Executive Office of Energy and Environmental Affairs, Anaerobic Digestion: Questions and Answers, 2013; Li, Park, and Zhu, 2011).

The biogas can be used simply to heat the digester to the required temperatures, or to heat the facility and generate electricity (called combined heat and power, or cogeneration). The biogas can also be further purified into compressed natural gas (CNG) to fuel vehicles (Massachusetts Executive Office of Energy and Environmental Affairs, Anaerobic Digestion: Questions and Answers, 2013) or used to dry out the digestate for disposal (Massachusetts Executive Office of Energy and Environmental Affairs, Biogas Production, 2013). In Scandanavia, most excess heat from the process is used for district heating (Zlobisz, 2010). The use of anaerobic digestion to produce energy falls under the larger categories of waste to energy, bioenergy, biofuel, or biomass, although these broader terms can include the burning of trash, wood, or other agricultural materials. Anaerobic digesters can be found at stand-alone organics recycling facilities or on site where their major feedstocks are located: wastewater treatment plants, farms, and food processing facilities (Massachusetts Executive Office of Energy and Environmental Affairs, Anaerobic Digestion: Questions and Answers, 2013).

Anaerobic digestion can turn a cost into a benefit. It reduces the volume of waste considerably, making it easier and cheaper to transport. It also reduces the odor and pathogen levels in the waste. It produces energy, and unlike other renewable energy technologies, it can be easily stored for later use (American Biogas Council, Benefits of Biogas). Additionally, it reduces greenhouse gas emissions from the disposal of organic waste and energy generation.

CODIGESTION OF FOOD WASTE

Often, anaerobic digesters are intended for use for a particular type of waste generated on site, whether that be manure, wastewater sludge, or food manufacturing by-products. However, codigestion of multiple feedstocks together can help to balance the carbon/nitrogen ratio and increase the biogas output up to three times. Food waste in particular has a high energy content (Wong, 2011; Breslin, 2013). While fats, oils, and greases (FOG) and food waste create the most biogas (American Biogas Council, Frequent Questions), these materials can also create high levels of ammonia and volatile fatty acids, and lower the pH of the system quickly, all of which interfere with the bacteria's activity. For these reasons, a combination of materials may actually create the best balance for optimal biogas yield (Khalid, 2011). The addition of food waste can also increase the rate of sludge volume reduction.

Keeping the feedstock consistent is important for maintaining an ideal environment for the bacteria (Li, Park, and Zhu, 2011). Volatility of inputs can prevent consistent biogas output, so variable food waste is less desirable to operators (Slater, 2014). There are three tiers of food waste, in ascending order of variability and difficulty of collection: industrial, small commercial, and residential (Snellings, 2014).

Pretreatment of food waste is necessary to reduce the particle size, make it easier for the bacteria to process, and prevent clogging of pumps (Li, Park, and Zhu, 2011; American Biogas Council, What Is Anaerobic Digestion?). In order for food waste to be processed by wet digesters (the most common in Massachusetts), it must be chopped or ground into smaller pieces, or even heated to break the cell walls, and mixed with water so that it can be pumped through pipes. To deal with these issues, existing digesters seeking to add food waste to their feedstock will need to install pretreatment equipment or have pretreatment done offsite (Li, Park, and Zhu, 2011).

Food waste constitutes approximately 21% of the municipal solid waste stream, and each year nearly 34 million tons of food gets wasted in the United States (Fitzgerald, 2011). Sending just half of America's food waste to anaerobic digesters would generate enough electricity to power 2.5 million homes (Royte, 2013).

TYPES OF DIGESTERS

WET VS. DRY

Anaerobic digestion is considered either wet or dry (also called solid state) depending on the amount of solids in the feedstock. There is some variation in the categorization of the makeup of wet and dry feedstocks, but generally less than 20% solids is considered wet and 20-45% solids is considered dry (Eastern Research Group, 2013; American Biogas Council, What Is Anaerobic Digestion?). Dry digesters have feedstocks that can be handled by a front-end loader, while feedstock for wet digesters is piped in (American Biogas Council, What Is Anaerobic Digestion?). Animal manure, wastewater sludge, and food manufacturing waste are considered wet, while table scraps and yard waste are considered dry, although food scraps can be slurried for use in wet digesters (Massachusetts Executive Office of Energy and Environmental Affairs, Anaerobic Digestion: Questions and Answers, 2013). Unlike wet digesters, dry digesters have no internal mixing, and less energy is required for heating them. Wet digesters have a larger capacity and three times shorter retention times. More than half the digesters in Europe are dry (Li, Park, and Zhu, 2011).

BATCH VS. CONTINUOUS

Batch digesters are the simplest and least expensive option. Most dry digesters are batch. In these, the feedstock is fed once into the digester and left alone until it is processed. These tend to produce less biogas, because gas production fluctuates depending on what stage in the process it is (Khalid, et al, 2011). Since methane can react explosively with oxygen, with batch digesters the methane must be completely purged from the reactor before opening it. Most facilities with batch digesters do not generate electricity and flare the methane to prevent it from escaping into the atmosphere (Li, Park, and Zhu, 2011). Continuously fed digesters are usually wet. They require removal of the finished digestate and gas and the addition of new feedstock regularly, so that gas production is constant (Khalid, et al, 2011). For this reason, continuous digesters are easier to pair with combined heat and power.

SINGLE-STAGE VS. MULTI-STAGE

Another way of categorizing digesters is by single-stage or multi-stage, in which the steps of the process take place either in just one container or in a container for each step (Khalid, et al, 2011). Single-stage digesters are typically simpler to design, build, and operate, as well as less expensive. However, the amount that can be added at any one time is limited by the ability of the methanogenic bacteria to tolerate the sudden drop in pH from rapid acid production during hydrolysis. Two-stage digesters separate hydrolysis from methanogenesis, allowing for higher loading rates from high nitrogen materials but requiring additional reactors and loading systems (American Biogas Council, What Is Anaerobic Digestion?). These are not heated or mixed, and are rarely used in newer plants (Appels, 2008).

COMPLETE MIX VS. PLUG FLOW

A complete mix digester is an enclosed tank with a mechanical, hydraulic, or gas mixing system. They work best with wet digestion (American Biogas Council, What Is Anaerobic Digestion?). A plug flow digester is a long cylindrical tank in which material progresses through in layers, with no mixing; however a modified plug flow uses vertical mixing. They are often used at dairy farms that collect manure by scraping (American Biogas Council, What Is Anaerobic Digestion?; U.S. Environmental Protection Agency, Recovering Value from Waste). Complete mix and modified plug flow designs are the most common on farms (U.S. Environmental Protection Agency, Agstar, 2013). Complete mix works best for smaller facilities; plug flow can be appropriate for larger ones (U.S. Environmental Protection Agency, 2010).

MESOPHILIC VS. THERMOPHILIC

Anaerobic digesters are also categorized as either mesophilic or thermophilic, depending on their temperature. Mesophilic systems run at a lower temperature (35 degrees C, or 95 degrees F). Because of this, less energy is required to heat it, and the bacteria levels are generally more stable, although processing time is longer. Thermophilic systems run at a higher temperature, around 55 degrees C, or 131 degrees F, and are faster (Khalid, et al, 2011; Karagiannidis, et al, 2009; Appels, 2008). They also offer improved dewatering, increased solids reduction, and increased destruction of pathogens. However, they require higher energy use to heat the digester, have a lower quality digestate, have more potential for odor, and are less stable, since the bacteria is especially sensitive to temperature fluctuations (Appels, 2008). Thermophilic is considered better for dry and plug flow digesters (Li, Park, and Zhu, 2011).

TYPES OF ELECTRIC GENERATORS

There are three main types of technology used to generate electricity at anaerobic digesters: turbines (gas, steam, or microturbines), fuel cells, and internal combustion engines. Decisions about what type of electric generator to use are based on size and cost. Gas turbines or internal combustion engines are the most common (Appels, 2008).

Microturbines are appropriate for smaller facilities, generating from 30 kW to 250 kW (Wong, 2011). Their cost is mid-range (Massachusetts Executive Office of Energy and Environmental Affairs, Biogas Production, 2013). They produce low levels of emissions and are relatively quiet. However, they have low electrical and thermal efficiencies, require significant biogas pretreatment and pressurization, and have a short service life. Additionally, warm weather and high elevation can reduce fuel efficiency (Brown and Caldwell, 2012).

Steam turbines are appropriate for larger facilities, generating from 50 kW to 250 MW. They require less biogas pretreatment because the steam drives the turbine rather than the expansion of the biogas (Wong, 2011). They also produce low levels of emissions and are very reliable and long lasting. However, their efficiency is low, they must be continually staffed, and they must have a large condenser to cool the steam for optimal performance (Brown and Caldwell, 2012).

Gas turbines are only appropriate for larger facilities, generating from 500 kW to 250 MW (Wong, 2011). They are a reliable, well-proven technology with high thermal efficiency that requires less frequent maintenance. Their emissions are relatively low and they do not require continual staffing. However, they require gas pressurization and specialized maintenance. Warm weather and high elevation can reduce fuel efficiency (Brown and Caldwell, 2012).

Fuel cells are appropriate for medium-sized facilities, generating 50 kW to 2 MW. They are highly efficient with exceptionally low emissions (Wong, 2011), frequently exempt from air permitting. They also have very high electrical power efficiency, are extremely quiet, and do not require continual staffing (Brown and Caldwell, 2012). However, they are the most expensive option (Massachusetts Executive Office of Energy and Environmental Affairs, Biogas Production, 2013) and require very high levels of biogas pretreatment, as well as highly specialized maintenance. They have short lives (five years), produce less recoverable heat, and require a lot of fresh water (Brown and Caldwell, 2012).

Internal combustion engines are appropriate for small to medium facilities, generating 10 kW to 5 MW (Wong, 2011). They are the lowest-cost option (Massachusetts Executive Office of Energy and Environmental Affairs, Biogas Production, 2013). They do not require biogas pretreatment and are a reliable, well-proven technology. They also have the greatest combined electrical and thermal efficiency and are easier to maintain. However, they do require continual cooling (Brown and Caldwell, 2012).

Another option is the Stirling engine, which is appropriate for smaller facilities, generating less than 200 kW. This is a reciprocating external combustion engine that operates on the temperature differentials on either side of the piston. This also requires cooling. These are well suited for biogas, because they do not require biogas pretreatment, are quiet, and have lower emissions. However, they are more expensive than internal combustion (Wong, 2011).

CHAPTER TWO: BENEFITS AND BARRIERS

BENEFITS

Anaerobic digestion/combined heat and power can turn a cost into a benefit. However, the benefits vary depending on the facility. They include lower/more stable energy costs, energy security, reduced sludge volume, revenue from sale of digestate, lower-cost food waste disposal, revenue from tipping fees, odor control, water quality protection, and greenhouse gas emissions reductions.

LOWER/MORE STABLE ENERGY COSTS

Facilities with anaerobic digestion can save on energy costs with combined heat and power (Slater, 2014). Nationwide, the cost to generate electricity at wastewater treatment plants ranges from 1.1 to 8.3 cents per kWh; retail electric rates range from 3.9 to more than 21 cents per kWh, so there are clear economic benefits to CHP, especially for larger facilities. The cost to generate electricity decreases as the generator increases in size (U.S. Environmental Protection Agency, Opportunities for Combined Heat and Power at Wastewater Treatment Facilities). In Massachusetts, net metering allows an electricity generator to feed any excess electricity back to the electric grid and receive credits to their electricity bills at near-market rates. Recent legislation (S.2395, 2012) added all anaerobic digestion facilities to the list of technologies eligible for net metering, rather than just agricultural digesters (Massachusetts Executive Office of Energy and Environmental Affairs, 2012). Therefore facilities can use the energy produced by AD/CHP to lower their energy bills, whether by using it directly or feeding it into the grid. Net metering also allows the facility to avoid the issue of storage of the electricity generated, which is a problem because of the lack of affordable long-term storage technologies. Because the cost of the energy generated with AD/CHP is consistent, it protects facilities from energy price volatility due to seasonal use fluctuations or shortages.

While net metering is a great option for facilities that will use all of the electricity generated, if a facility generates more than it uses, a power purchase agreement (PPA) is another option. With a PPA, another entity buys the electricity generated, or a portion of it. As with net metering, this can only be done if both are within the same utility service area and load zone. With PPAs, the rate for electricity is whatever is agreed upon by the two parties, rather than a regularly changing rate offered by the utility. This is the option that standalone facilities would use, or farm or wastewater facilities that expand to generate more electricity than they use (for instance, with the addition of food waste).

ENERGY SECURITY

The energy generated by AD/CHP contributes to resilience of essential municipal services. If the facility is set up for islanding, or disconnecting from the grid in the event of a power outage in order to continue generating electricity for use on site, it can ensure that wastewater processing can continue in the event of a power outage, rather than having to discharge untreated or partially treated sewage into waterways. As renewable energy, it's a baseload source, rather than intermittent, like wind and solar, so energy storage is not an issue (American Biogas Council, Benefits of Biogas; U.S. Environmental Protection Agency, 2009).

REDUCED SLUDGE VOLUME

Even without combined heat and power, anaerobic digestion is useful by itself for reducing the volume of wastewater sludge and manure, as well as reducing pathogens (Slater, 2014; American Biogas Council, What Is Anaerobic Digestion?). Since sludge disposal is one of the largest expenses for a wastewater treatment facility, the savings from sludge reduction alone can make anaerobic digestion worthwhile (Wong, 2011).

VALUE OF DIGESTATE

Economic benefits of anaerobic digestion include valuable byproducts, such as fertilizer, animal bedding, or compost. While processing of digestate into fertilizer can be expensive, the sale of it can offset the cost of digestate disposal, which is one the largest expenses for a wastewater treatment facility. For farms, liquid digestate can reduce or replace purchased fertilizer, a significant operating cost. The digestate from dry digesters, on the other hand, can be used for cattle bedding, also a potential savings (U.S. Environmental Protection Agency, 2011).

LOWER-COST FOOD WASTE DISPOSAL

Disposal of source-separated food waste, whether through animal feeding, composting, or anaerobic digestion, is cheaper than municipal solid waste disposal. Regular waste disposal fees vary based on market price and individual contracts; however, they often hover between $60 and $80 per ton. Fees for food waste disposal can be as little as $20 per ton, or free as part of a public/private partnership, depending on the arrangement that is made with the facility. Additionally, food waste is denser than other municipal solid waste, so its removal from the waste stream leaves a much lighter load to be sent to landfill or incinerator at the regular price.

REVENUE FROM TIPPING FEES

Facilities that accept organic waste from other entities, such as other municipalities or private businesses, can charge tipping fees for that waste. These depend on market price and individual contracts, but often run around $20/ton for food waste.

ODOR CONTROL

For farms in particular, environmental benefits of anaerobic digestion include odor control, since the primary sources of odor are volatile organic acids and hydrogen sulfide, which are either consumed during the anaerobic digestion process or filtered out before combustion of the gas (U.S. Environmental Protection Agency, 2011).

WATER QUALITY PROTECTION

Anaerobic digestion helps to protect waterways near farms and wastewater treatment plants, since it destroys more than 90% of disease-causing bacteria and reduces biological oxygen demand in the wastewater (U.S. Environmental Protection Agency, 2011).

GREENHOUSE GAS EMISSIONS REDUCTIONS

On a larger level, anaerobic digestion reduces methane emissions. Methane represents 1/3 of manmade climate forcing (U.S. Environmental Protection Agency, Market Opportunities for Biogas Recovery Systems, 2011), having 21 times more global warming potential than carbon dioxide over a time horizon of 100 years, or 72 times over a time horizon of 20 years. Recognizing this, the Obama administration recently announced a national plan to reduce methane emissions, and anaerobic digestion is one method to do so. The greenhouse gas emissions reduction of anaerobic digestion/combined heat and power comes mainly from avoided landfill emissions and replacement of fossil fuels (United Nations Environmental Programme, 2010), as well as synthetic fertilizer replacement and livestock manure capture.

On a global scale, the waste management sector represented 3-5% of total anthropogenic emissions in 2005 (United Nations Environment Programme, 2010). Anaerobic digestion occurs naturally in controlled landfills, where the absence of oxygen favors methane-producing bacteria, and the breakdown of organic materials creates biogas that can escape into the air over time. This is the number one source of methane in the waste sector. (Wastewater management is the number two source.) Landfill gas capture systems reduce this amount by 50-80% in developed countries. Landfill gas capture and anaerobic digestion are complementary, because existing landfills will continue to emit methane gradually over many years, even if all new food waste is diverted from them. Landfill gas capture systems and anaerobic digestion facilities can even be co-located and share the same generators to reduce cost (United Nations Environment Programme, 2010).

While AD/CHP facilities do have carbon dioxide emissions as they burn biogas for energy, the emissions associated with them are considered biogenic because they are from natural sources, rather than manmade (anthropogenic), so they are not counted against a generator's carbon footprint (Climate Action Reserve, 2014; Brown and Caldwell, 2012). On a national scale, the technical potential for additional CHP at wastewater treatment plants is over 400 MW and 38,000 MMBtu/day. This could prevent approximately 3 million metric tons of carbon dioxide emissions annually, equivalent to the emissions of approximately 596,000 passenger vehicles. Having energy generation on site also avoids the average 6.2% line loss (U.S. Environmental Protection Agency, Opportunities for Combined Heat and Power at Wastewater Treatment Facilities, 2011).

Digestate applied to land replaces synthetic fertilizers, which are energy-intensive to manufacture, as well as peat, which is energy-intensive to extract and also generates methane emissions (United Nations Environment Programme, 2010).

Methane from livestock manure represents 7% of global methane emissions and 8% of U.S. methane emissions (U.S. Environmental Protection Agency, 2011). In North America, anaerobic digestion could cut the methane emissions from livestock manure in half (Klingler, 1998). Developers working on digesters on five farms in Massachusetts estimated that the project would avoid 27,000 metric tons of carbon dioxide equivalent per year, or about half the emissions originally produced by them. This is roughly equivalent to the emissions of about 5,000 cars per year (Morris, 2010).

Research on codigestion of the municipal food waste with sewage sludge and energy crops has shown that methane savings are achieved only when codigestion does not involve transportation of waste over long distances (Zglobisz, 2010). Thus, siting facilities appropriately is important.

BARRIERS

While anaerobic digestion/combined heat and power facilities offer many benefits, they are large capital projects that can be difficult to implement for many reasons. Challenges include siting, facility size, permitting, feedstock availability, digestate disposal, staffing, public reaction, and cost (Slater, 2014; Kilbourn, 2014).

SITING

Consideration of where to locate anaerobic digestion facilities is important, because siting is one of the biggest obstacles. Ideally, half of the feedstock would be located on site. To balance the energy used for transportation of any outside feedstock, facilities should be within 30 miles of their sources (or less, depending on the type of feedstock). To prevent negative public reaction, they should be sited near highways and away from residents. To reduce interconnection costs, which are borne by the generator, they should have access to utilities, which is less likely in more rural areas (Barad, 2014; U.S. Environmental Protection Agency, Opportunities for Combined Heat and Power at Wastewater Treatment Facilities). The relatively large footprint of anaerobic digestion facilities, including the reactors themselves, master control centers, storage tanks, generators, and/or pretreatment facilities, means that they require a minimum of 3-4 acres. Existing facilities may have difficulty making room for this equipment. Egg-shaped digesters can be built higher than silo designs, fitting a larger capacity into a smaller footprint (Wong, 2011).

Potential sites on municipally owned property include wastewater treatment plants and landfills. Potential sites on privately owned property include dairy/pig farms and food manufacturing facilities.

WASTEWATER TREATMENT PLANTS

Wastewater and water utilities can represent 30-60% of a municipality's energy bill (Wong, 2011) and they account for 4% of the energy used in the U.S. (Brown and Caldwell, 2012). Electricity can be more than 25% of the total operating cost for a wastewater treatment plant, and CHP has the potential to offset its electricity consumption by 40% (Brown and Caldwell, 2012), so AD/CHP can deliver significant savings. Additionally, sludge disposal can represent up to half of a wastewater treatment plant's operating costs, and anaerobic digestion can reduce the volume of such sludge significantly. It can also offset the expense of sludge disposal, as pelletized digestate can be sold for fertilizer (Appels, 2008).

There are about 1,500 anaerobic digesters at wastewater treatment plants in the United States; however, only about 250 of these use the biogas for heat or electricity. The others simply flare (burn) their biogas so that it is not released into the atmosphere (American Biogas Council, Frequent Questions).

Anaerobic digestion is potentially economically feasible for wastewater treatment plants that process at least 1 million gallons per day. There are over 3,500 wastewater treatment plants of that size in the United States (of over 17,000 total plants) (American Biogas Council, Frequent

Questions). While combined heat and power is not as cost effective in smaller facilities in colder climates, such facilities can reap non-energy benefits from anaerobic digestion by itself, such as reduction in the volume of sludge to be disposed (Wong, 2011).

It is important to keep in mind that unlike standalone anaerobic digestion facilities, wastewater treatment plants require excess capacity in order to deal with peak flows, or redundancy in order to maintain service reliability in the event of equipment failure. Therefore, excess capacity at a wastewater treatment plant does not necessarily indicate an opportunity for the addition of food waste.

LANDFILLS

Anaerobic digestion can be appropriate for both active and closed landfills. Siting facilities alongside landfill gas projects with existing generation equipment can reduce capital cost by as much as $1 million (Kilbourn, 2014). There are currently 626 operational landfill methane projects nationwide, generating 2,032 MW and 317 mmscfd of gas. There are 21 in Massachusetts (U.S. Environmental Protection Agency, Landfill Methane Outreach Program). While closed landfills do not have the benefit of existing generation equipment, they also represent an opportunity to put unused municipal property to profitable use, and they generally also have the benefit of pre-existing permits and locations away from residential areas. However, in order to build on a capped landfill, pilings must be placed through the waste as a foundation for the digester, and this may be prohibitively expensive (Snellings, 2014).

FARMS

Nationwide, there are more than 2,500 dairy farms and 5,500 pig farms that could implement AD/CHP, with a combined potential for 1,314,441 MWh and 68,783,000 MMBtu per year. Roughly 500 cows or 2,000 pigs are recommended in order for AD/CHP to be economically feasible. Compared to other states, Massachusetts is not considered to have much potential for farm anaerobic digestion, with less than 15 candidate dairy farms and less than 15 candidate pig farms (U.S. Environmental Protection Agency, 2011). However, farms can be especially attractive to developers because of the opportunity represented by feedstock collection and digestate disposal on site (Kilbourn, 2014).

FOOD MANUFACTURERS

Food manufacturers and distributors also have the benefit of an onsite feedstock. This model is the least likely to require outside subsidies, because they have control over most of the variables (Barad, 2014). For these companies, digesters represent a way to save money, reduce the amount of wastewater discharged to the municipal sewer system, or improve the quality of wastewater (Snellings, 2014), and they are less likely to accept outside feedstock. Supermarket distributors require depackaging equipment to remove food from its containers, which in Massachusetts will likely need to be added onsite, because this is not a service that haulers offer in the state.

FACILITY SIZE

In colder climates, wastewater treatment plants with a flow of less than 1-2 million gallons per day are generally considered not large enough to produce sufficient biogas to make the installation of CHP cost-effective (Massachusetts Executive Office of Energy and Environmental Affairs, Biogas Production, 2013; Wong, 2011). The vast majority of economic potential at wastewater treatment plants is in large (greater than 30 MGD) plants that can support larger CHP units, unless electricity prices are extremely high (U.S. Environmental Protection

Agency, Opportunities for Combined Heat and Power at Wastewater Treatment Facilities) or other factors mitigate the cost. For food waste by itself, 50,000 tons per year is recommended. If the amount is more in the range of 10,000-20,000 tons per year, it's generally more cost-effective to compost it. Digesters on farms are generally smaller and easier to operate, with no nutrient cleanup such as wastewater plants require. For food manufacturing businesses, digesters are cost management strategies, to minimize the quantity and reduce the dissolved oxygen demand and chemical oxygen demand of material put into the sewer system. Supermarket distribution facilities are large enough to be candidates, but not individual supermarkets (Snellings, 2014). However, every project is different, so generalized thresholds are difficult to formulate. Each proposed facility should be evaluated on its own merits (Kilbourn, 2014).

There are only 13 small-scale projects in the U.S (Lansing, 2010), and there has yet to be an example of one in Massachusetts. When ambient air and sludge temperatures are low, it takes more energy to heat the digesters. In most climates, in the winter there is little recovered heat available for space heating after heating the digesters (U.S Environmental Protection Agency, Opportunities for Combined Heat and Power at Wastewater Treatment Facilities). Small-scale cold-climate projects in the United States have been research or demonstration projects, such as a prototype Compact Organic Waste Solution tested in partnership with the University of Michigan's Anaerobic Digestion Research and Education Center, which could process 100 tons per year of organic waste (ReGenerate, 2012). MassCEC has put together a small-scale (0.5-30 tons per day) vendor directory for those who may be interested in investigating such facilities (Eastern Research Group, 2013).

By combining multiple waste streams or combining the feedstock from a larger area, the capacity of smaller facilities may be increased to the point that CHP systems will be cost-effective. Smaller wastewater treatment plants or farms can make CHP economically feasible by adding organic waste with high biological oxygen demand (BOD) to their wastewater (Barad, 2014; U.S. Environmental Protection Agency, Opportunities for Combined Heat and Power at Wastewater Treatment Facilities). Economies of scale mean that regional facilities may make more sense, particularly with food waste and wastewater treatment plants, despite the longer distance to transport feedstock (Slater, 2014). In this case, operational changes and challenges would be limited to a single facility, and capital costs could be shared or financed by a larger entity (Wong, 2011).

PERMITTING

Anaerobic digestion facilities are industrial facilities and require multiple permits in order to ensure that they meet pollution standards. The permitting process can be a long, expensive one, so developers should understand what is required at the outset.

MASSACHUSETTS GENERAL PERMIT

Massachusetts recently revised its site assignment regulations to encourage food waste recycling by lifting the requirement for site assignments for some in favor of a general permit. Previously, a site assignment for solid waste facilities had to be approved by the local board of health. The new regulations state that agricultural units, composting facilities that accept less than 10 tons of organic material per week, and municipal collection centers that accept less than one ton per day are exempt from the permitting process. Facilities that receive no more than 100 tons of organic material from off site per day are eligible for a general permit for recycling, composting, or aerobic or anaerobic digestion operations. Larger facilities are still required to get a site assignment; facility permit; or recycling, composting, or conversion permit (310 CMR 16.00, 2012). The Stop ‘n’ Shop distribution center in Freetown is the first to apply under the new rules (Barad, 2014).

Organic materials are separated into Group 1 and Group 2. Group 1 organic materials include yard waste, cardboard, paper products, and wood. Group 2 organic materials are the kind that could be sent to anaerobic digesters: vegetables, food material, grass clippings, green plant material, fish waste, manure, and solid and liquid digestate. In order to be eligible for a general permit, Group 2 materials must be delivered via sealed tank and transferred using direct connection (such as a hose) if they are more than 15 tons per day (310 CMR 16.00, 2012).

Existing disposal or handling facilities (even closed ones) can do recycling, composting, or conversion without a new permit; however, their existing site assignment must be modified if the operation is not consistent with it. A wastewater treatment plant may accept and process source-separated organic material with prior written approval of the DEP (310 CMR 16.00, 2012).

OTHER PERMITS

Energy generators must be certified by the EPA to meet federal emissions standards. State air permits may be necessary if the generators emit enough air pollution to meet federal emissions thresholds. Concentrated animal feeding operations require water discharge permits. Facilities that digest more than just manure must also meet federal standards for solid waste under the Resource Conservation and Recovery Act (U.S. Environmental Protection Agency, Permitting Practices for Co-Digestion Anaerobic Digester Systems, 2012). The Massachusetts Environmental Policy Act (301 CMR 11.00). also applies. In some cases, projects would have to submit an Environmental Impact Report detailing impact to wetlands, endangered species, conservation land, and air quality emissions. The Massachusetts Contingency Plan (310 CMR 40.0000) requires that proposed facilities need a licensed site professional to evaluate their impact on human health, safety, and the environment (Fitzgerald, 2013). Additionally, approval from the Massachusetts Department of Agricultural Resources under 310 CMR 32 is required to use the digestate or effluent as fertilizer (Wong, 2011; Slater, 2014).

Local requirements including zoning limitations (Fitzgerald, 2013), construction permits (U.S. Environmental Protection Agency, Permitting practices for co-digestion anaerobic digester systems, 2012), and board of health review. Although it should be noted that facilities that receive general permits from MassDEP are not required to get a site assignment from the local board of health, communication with the board of health and attention to their concerns helps to make the process go smoothly. The board of health still has jurisdiction over any nuisance that develops and may inspect the facility for such nuisances (Barad, 2014).

FEEDSTOCK AVAILABILITY

Potential feedstock and its quantity must be identified early on in the planning process (Kilbourn, 2014; Slater, 2014). Possible feedstocks include wastewater sludge, cattle manure, food manufacturing residues, and food waste. Farms and wastewater treatment plants have the majority of their feedstock on site, but if they wish to add food waste, or if standalone digesters are developed that process food waste alone, a sufficient quantity of feedstock must be secured in order to justify the investment. Facilities that rely on food waste would need to be located near population centers (American Biogas Council, Food Waste). A population minimum of 1 million is recommended to generate enough food waste for a standalone facility (Snellings, 2014). For reference, the population of Massachusetts is 6.6 million. When regional incinerators were developed in the state, they had flow control, meaning that towns were required to send a certain amount of feedstock to the incinerators. This is not happening with anaerobic digesters (Barad, 2014). In order to ensure reliable feedstock for a facility with such high capital cost, anaerobic digestion facilities generally want long-term contracts (5-10 years) that guarantee the organic quality, the volume or weight, and frequency of delivery (U.S. Environmental Protection Agency, Increasing Anaerobic Digestion Performance with Codigestion). Such long-term contracts help to secure financing from private sources (Barad, 2014).

Comparing energy output to the energy required for transportation, the maximum transportation radius of various feedstocks ranges from 10 to 40 kilometers, or roughly 6 to 25 miles, depending on whether the feedstock is wet or dry (Höhn, et al, 2013; Dagnall, et al, 2000; Danall, et al, 1995). For cattle manure, transportation of even 10-20 kilometers decreases its relative energy output tremendously. For food residues, relative output decreases abruptly after 50 kilometers, and is still quite low after 30 kilometers (Poschl, Ward, and Owende, 2010).

DIGESTATE DISPOSAL

What to do with the resulting digestate, in terms of storage, transportation, or use, is one of the biggest obstacles for potential AD/CHP facilities (Kilbourn, 2014), and one that is often neglected in discussions about it (Slater, 2014). Pathogens are removed, and the solids volume is reduced by half, but there is still residual digestate, and the liquid is still high in nutrients, so it must be further treated before it can be discharged. Depending on the type of digester and feedstock, the digestate will be very different. It can either be composted (cured) on site or off, sent to a landfill or incinerator, used as liquid fertilizer, or dewatered and pelletized for fertilizer. Digestate from manure or food waste can be spread on fields directly, but wastewater sludge must be further processed, because it could contain toxins such as heavy metals (Slater, 2014; Wong, 2011; Khalid, 2011). These can be difficult and expensive to remove (Slater, 2014). Because of this, wastewater digestate is subject to more stringent permitting restrictions than farm or food waste digestate.

STAFFING

It is unlikely that existing municipal staff will have experience with anaerobic digestion technology (Wong, 2011; U.S. Environmental Protection Agency, Opportunities for Combined Heat and Power at Wastewater Treatment Facilities). For this reason, public/private partnerships to operate (or own and operate) such facilities are common. If this is not the case, municipalities should be sure to build long-term maintenance into the contract so that assistance will be available during startup, as well as during operation if there are problems (Slater, 2014).

PUBLIC REACTION

Concerns about AD/CHP facilities primarily are expressed by abutters to the facility, as well as residents who live along roads used to access the facility. Public concerns tend to focus on potential nuisance conditions, such as hours of operation, odor, noise, and dust (Kilbourn, 2014), as well as any risk of explosion (Beecher, 2012). For this reason, sites near residential areas are undesirable. Much of the concern is due to a lack of understanding (Barad, 2014). Because the digesters are air tight, odor from them is not an issue. Pre- and post-processing, such as receiving areas for food waste and storage containers, should use biofilters and negatively pressured air to prevent odor escaping (American Biogas Council, Food Waste). Traffic concerns mean that sites near major roads are optimal (Dagnall, 2000); however, the tanker trucks used look more like oil trucks than the garbage trucks that residents may imagine. Because most of the concerns have more to do with public perception than reality, public education is an essential component of AD/CHP development. Technology used decades ago has left images in the public consciousness of a smelly operation. Modern AD/CHP technology has much more in common with a light or medium industrial facility than a solid waste dump.

COST

Capital costs for anaerobic digestion facilities are large. They vary considerably based on the characteristics of each project, such as reactor choice, generator choice, digestate disposal, and whether there's an existing facility. The average U.S. digester costs $1.5 million (Lansing, 2010), and combined heat and power is an additional cost. Full systems can be in the $8-10 million range. Wastewater treatment plant costs in Massachusetts have ranged from $5 to $14 million, illustrating that it can be easier to start from scratch than to integrate with an older system (Barad, 2014).

The long-term financial benefits of an AD/CHP facility should balance the startup costs. Energy costs—already high in the Northeast—are anticipated to increase with time, so a stable long-term price for energy could be very attractive to local governments (Wong, 2011). However, contrary to popular perception, income from electricity generation is not enough to drive such a project, and it likely will not be unless grid prices are much higher (Kilbourn, 2014). Sludge could also become a revenue generator rather than just an expense (Wong, 2011).

In the wastewater realm, capital costs for combined sewer overflow replacement take precedence over anaerobic digestion, as does the cost to meet more stringent discharge requirements. Public-private partnerships can be a cost-effective alternative to municipal ownership (Wong, 2011). Developers are often looking for payback within 10 years (Snellings, 2014). Investors in a five-farm group in Massachusetts found that a management LLC reduced the risk to any one entity, with an estimated return on investment of 9 to 15% (Morris, 2010). Long-term contracts for electricity, RECs, and food waste are generally required in order to assure investors that the facility has a stable stream of income and feedstock (Barad, 2014).

INCENTIVES

It's unlikely that much private investment in anaerobic digestion would occur without some sort of government subsidy, especially at small scales, due to feedstock insecurity, high investment risk, and high capital expenditure (Zlobisz, 2010). Incentives are available from the federal and state government for audits, feasibility studies, and facility design (Wong, 2011).

There are multiple federal incentives for anaerobic digestion. The EPA/USDA AgSTAR program offers information and technical assistance for on-farm digesters. The EPA's Global Methane Initiative is another informational program that creates an international network to remove barriers for methane emissions reduction projects. The USDA's Advanced Biofuel Payment Program provides payments to producers of biofuels, and its Rural Energy for America Program provides loan guarantees and grants to rural agricultural producers for renewable energy systems (Fitzgerald, 2013). The Northeast Combined Heat and Power Application Center conducts audits for plants that already have anaerobic digestion (Wong, 2011).

In Massachusetts, more funding has been available for rural and agricultural use than municipal, although with the incipient food waste ban, available funding for municipal projects has expanded. The AgEnergy/Agriculture Environmental Enhancement Program is a renewable energy grant program for Massachusetts farms, up to $30,000. MassDEP's Recycling Loan Fund provides flexible lending programs to aid with the purchase of machinery and equipment for organics recycling and now includes $3 million specifically for AD. The Clean Water State Revolving Loan Fund offers 2% interest loans for planning and construction of projects. MassDEP's Sustainable Materials Recovery Program offers grants to public entities for municipal solid waste diversion (Fitzgerald, 2013). DOER's Green Communities Division offers competitive grants for energy projects to municipalities that have been certified as Green

Communities. MassCEC's Commonwealth Organics-to-Energy program offers technical assistance grants for public entities, and design and construction grants for both public and private entities.

MassCEC in particular is looking for entities that already have a site in mind and material to digest. Many facilities have received grants for feasibility studies; however, almost all of them are behind schedule. Eight wastewater treatment plants are looking into adding AD/CHP or expanding their existing anaerobic digestion to include food waste. These are mostly small facilities (under 5 MGD), and MasCEC is waiting to see the results of these studies before funding new ones (Barad, 2014).

CHAPTER THREE: MASSACHUSETTS CONTEXT

MASSACHUSETTS FOOD WASTE BAN

In the face of dwindling landfill capacity, Massachusetts has been diverting an increasing amount of material for recycling. Massachusetts landfill capacity was just 2 million tons in 2009 and is expected to drop to 600,000 tons by 2020 (Wong, 2011). The Massachusetts Solid Waste Master Plan set the goal of reducing total waste disposed of per year by 30% (5.2 million tons) by 2020. As part of that goal, it strives to decrease organic materials sent to landfills or incinerators by 35%, or an additional 350,000 tons per year, by 2020, for a total of one million tons of organic waste diverted (Massachusetts Department of Environmental Protection, 2014; Massachusetts Executive Office of Energy and Environmental Affairs, About the Task Force on Building Organics Capacity, 2013; Eastern Research Group, 2013).

There are already relatively high rates of yard waste diversion (Massachusetts Department of Environmental Protection, 2014), possible because collecting and composting it is more attractive, since it is not made of putrescible material, which may smell as it decomposes. Food waste represented 18% of municipal solid waste sent to landfills in 2007 (Wong, 2011), and organics make up more than 25% of the waste stream in Massachusetts, after recycling (Massachusetts Executive Office of Energy and Environmental Affairs, Patrick Administration Finalizes Commercial Organic Waste Disposal Ban; Massachusetts Department of Environmental Protection, 2014). A 2002 report identified 880,000 tons of food waste generated per year in Massachusetts. Food manufacturing, supermarkets, and restaurants were the three major types of generators, and 56%, or 500,000 tons, were the result of food manufacturing (Draper/Lennon Inc., 2002). To help meet Massachusetts' goal, a commercial food waste ban will go into effect in October 2014. This affects large institutions that discard at least one ton of food waste per week, approximately 1,700 businesses and institutions in Massachusetts (Massachusetts Executive Office of Energy and Environmental Affairs, Patrick Administration Finalizes Commercial Food Waste Disposal Ban). To help visualize this, one ton per week equals roughly two 55-gallon drums per day (O'Brien and Patneaude, 2014). To assist institutions in figuring out whether the ban applies to them, the Massachusetts Department of Environmental Protection has supplied rough estimates for the threshold of customers served per type of institution:

Type of Institution	Estimated Threshold
College or University	
Residential	734 students
Non-residential	2,751 students
Secondary School	4,000 students
Hospital	84 beds
Nursing Home	159 beds
Hotel	286 guests
Restaurant	70 full-time employees
Supermarket	35 full-time employees
Venues and Events	476 seats
Correctional Facility	286 inmates

Figure 3: Organics Waste Ban Guidance (Recycling Works, 2014)

When the waste ban was announced, MassDEP sent a letter to 2,000 entities that will likely be affected, informing them of the new regulation and the assistance available to them (Pontani, 2014). Assistance in complying with the food waste ban, including more detailed calculations to estimate whether it applies to a particular situation, is available through Recycling Works (Recycling Works, 2014). Recycling Works connects generators with haulers and processors, helping them to look at cost analysis and staff training (Pontani, 2014).

The Patrick administration is providing technical assistance and up to $1 million in grants to help site composting and anaerobic digestion operations on farms, wastewater treatment plants, and other public and private locations (Massachusetts Executive Office of Energy and Environmental Affairs, Patrick Administration Finalizes Commercial Food Waste Disposal Ban). More than $1 million was already awarded in the last quarter of 2012 through MassDEP's Sustainable Materials Recovery Program for processing capacity development and commercial collection piloting (Clean Energy Results, 2013).

Many large businesses and institutions have already implemented food waste separation as a cost-saving and environmental measure. A partnership between MassDEP and the Massachusetts Food Association has led to 300 supermarkets implementing food waste separation programs, saving them up to $20,000 per year per location (Massachusetts Executive Office of Energy and Environmental Affairs, Patrick Administration Finalizes Commercial Food Waste Organics Disposal Ban). For large food waste generators (one ton), separating organics makes financial sense, or is at least cost neutral. It also satisfied a customer demand (Pontani, 2014).

As of June 2013, MassDEP lists 28 permitted food waste processers in the state, most of them farms composting less than 15 tons per day. Jordan Farms in Rutland is the only anaerobic digestion facility listed that accepts food waste (Massachusetts Department of Environmental Protection, Permitted Food Waste Processors), although since then Barstow's Longview Farm and Pine Island Farm have both gone online. None of the three currently accept post-consumer food waste.

Alternative methods for disposal include donations of unused but good food to soup kitchens or food banks; feeding food waste to livestock, in particular pigs; or composting. All three of these options are cheaper than anaerobic digestion, and the first two may be considered more optimal, since they use food as food (Kilbourn, 2014). In terms of greenhouse gas emissions reduction, composting is less optimal than anaerobic digestion (Fitzgerald, 2013), since anaerobic digestion emits a quarter of the methane that composting does (United Nations

Environment Programme, 2010). However, there are far more existing composting facilities than there are anaerobic digesters, and there is extra capacity in them, although currently not enough for the amount of food waste that will be diverted due to the ban. Since composting is simpler and cheaper to set up, it is likely that composting capacity will expand before anaerobic digestion. It is anticipated that compliance with the food waste ban will grow incrementally, allowing the market to catch up to the legislation (Kilbourn, 2014).

There is the real possibility of food waste being sent to facilities outside of Massachusetts. Exeter Agri-Energy in Exeter, Maine is soliciting food waste from as far away as northern Massachusetts, and an anaerobic digestion facility planned for Johnstown, Rhode Island is less than 18 miles from the border and is anticipating its wasteshed to include southern Massachusetts. Longer transportation distances are less than ideal in terms of efficiency, since there is a potential negative externality in greenhouse gas emissions if transporting the food waste requires more energy than is embodied in the feedstock. Depending on the energy content of the feedstock, maximum efficient transportation distance can be as little as 20 miles. This would usually be reflected in the cost/benefit analysis of acquiring the feedstock; however, various market conditions could make it cost-effective for facilities to transport feedstock farther than is ideal. For instance, Exeter Agri-Energy hauls their own food waste and purifies the biogas into LNG to fuel their trucks (Barad, 2014).

OTHER FOOD WASTE BANS

Germany gradually banned the landfilling of untreated organic waste from 1990 to 2005 (United Nations Environment Programme, 2010), and the European Union's Landfill Directive of 1999 set a goal of reducing the landfilling of biodegradable municipal waste to 35% of 1995 levels by 2016, which may be one reason why anaerobic digestion has become so common there.

Europe now has more than 10,000 digesters (Breslin, 2013). Anaerobic digestion is used to treat more than 10% of organic waste in some European countries (Li, Park, and Zhu, 2011).

Vermont also has a food waste ban (Royte, 2013). To encourage the development of anaerobic digestion, Vermont offers the Clean Energy Development Fund, as well as Green Mountain Power's Cow Power program, in which customers can voluntarily pay an extra 4¢/kWh for electricity generated by farm digester gas (Fitzgerald, 2013).

Connecticut's food waste ban of 2011 is similar to that of Massachusetts, although its threshold is lower. As of January 2014, it requires that entities that generate 104 tons per year of food waste divert it from landfills. It includes an exception for entities that are not located within 20 miles of an organics recycling facility. Connecticut's Clean Energy Finance and Investment Authority also began an Anaerobic Digestion Pilot Program in June 2013, a 3-year, $5 million program to develop AD facilities (Fitzgerald, 2013).

In its upcoming food waste ban, Rhode Island is also including an exception for entities that do not have access to an organics disposal facility within 20 miles. However, the ban applies to all waste generators, including residents. It will begin to be enforced in 2020 and mandates that solid waste processers offer services for food waste and that haulers must offer curbside collection of food waste by 2017 (Fitzgerald, 2013).

A 20-mile exception seems reasonable in light of the current undeveloped market in Massachusetts; however, it could also serve to reduce demand for the development of such a market. Massachusetts has not included that exception in its food waste ban.

RESIDENTIAL FOOD WASTE COLLECTION

Although the food waste ban currently only affects entities with more than a ton of food waste per week, it is expected that the ban may eventually expand to include smaller entities and even residential waste. In the same way that many large entities already diverted their food waste before the ban, for financial as well as environmental reasons, some municipalities have already begun residential food waste collection. The town of Hamilton has begun weekly collection of residential food waste. The City of Cambridge is piloting residential food waste collection in one section of the city. MassDEP is offering grants for residential collection programs to encourage more municipalities to do so. Combining residential food waste collection with an anaerobic digestion facility may present an opportunity for municipalities to dispose of food waste less expensively and reduce electricity costs.

EXISTING FACILITIES

Anaerobic digestion is common in Europe and on the rise in the United States (Massachusetts Executive Office of Energy and Environmental Affairs, 2013). Nationwide, AD/CHP can be found at more than 250 wastewater treatment plants and 202 farms (U.S. Environmental Protection Agency, Agstar, 2013). California and New York both are ahead of the curve (Wong, 2011). Almost 12,000 sites in the United States have potential for development, including more than 540 landfill projects, farms, wastewater treatment plants, and industrial sites like food and beverage processors (Breslin, 2013). CHP is considered to be technically feasible at 1,351 wastewater treatment plants and economically attractive (with payback of seven years or less) at between 257 and 662 of those sites (U.S. Environmental Protection Agency, Opportunities for Combined Heat and Power at Wastewater Treatment Facilities). Anaerobic digestion was used at wastewater treatment plants as early as the 1940s, but when secondary treatment was required starting in the 1970s and 1980s because of the Clean Water Act, it led to process upsets and odor control problems. Most of those digesters have been shut down, but anaerobic digestion's reputation was damaged because of it, even though processes are now better adapted to manage secondary sludge (Wong, 2011). The failure rate since the 1990s has been high (75%) due to poor maintenance and operational problems (Zglobisz, 2010). Also, the lower cost of energy in the 1990s made CHP less cost-effective.

In Massachusetts, three wastewater treatment plants have AD/CHP installed: Deer Island, Pittsfield, and Fairhaven. The Greater Lawrence Sanitary District does not generate electricity from its biogas, but it does use it to dewater sludge for fertilizer. Three farms have AD/CHP installed, and codigest food waste: Jordan Dairy Farms in Rutland, Pine Island Farm in Sheffield, and Barstow's Longview Farm in Hadley. Deer Island is planning on starting a pilot food waste program within the next year. Additionally, AD/CHP can be found at industrial food processing facilities: Ken's Foods in Framingham, Garelick Farms/Dean Foods in Franklin and Lynn. Outside of Massachusetts, farm-based digesters in Exeter and Clinton, Maine, accept food waste, and in Essex Junction, Vermont, a wastewater treatment plant accepts food waste (Fitzgerald, 2013).

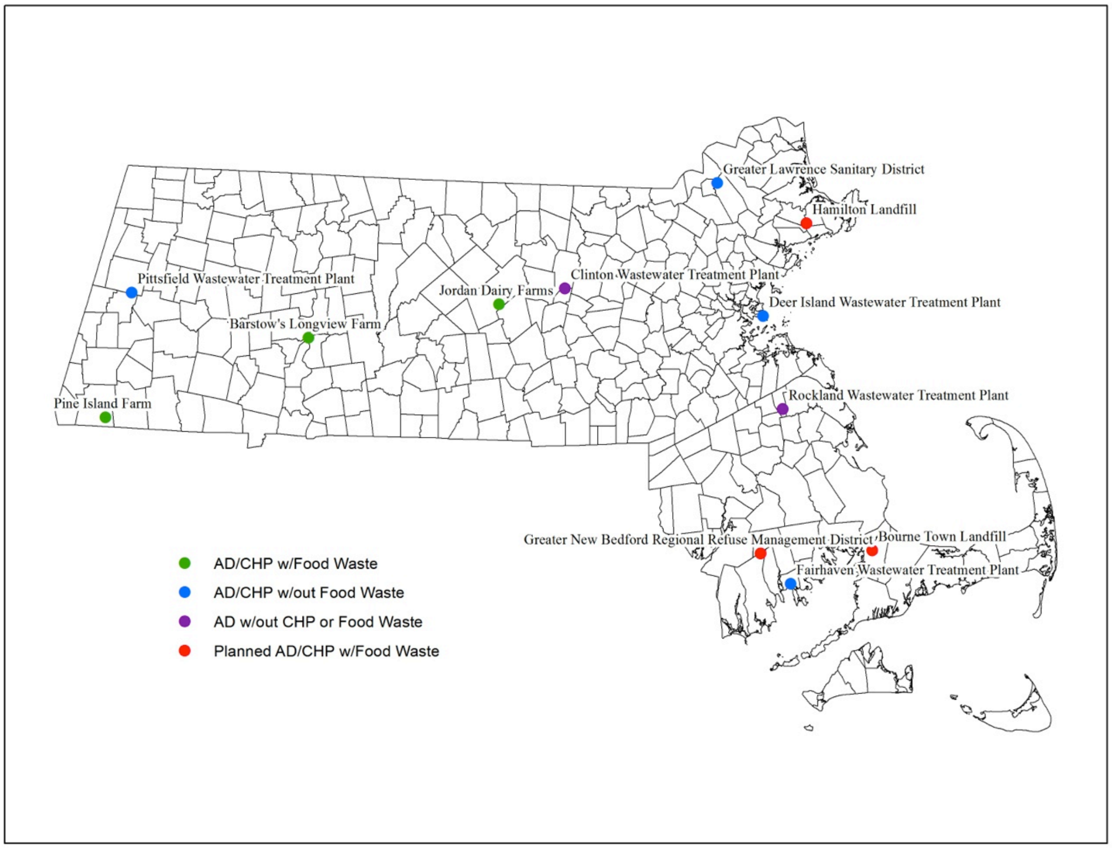

Figure 4: AD/CHP in Massachusetts

PLANNED FACILITIES

There are currently many locations in Massachusetts considering AD/CHP facilities that codigest food waste. Uncertainties in the market; large capital costs; and long time frames for design, permitting, and construction mean that many have continued to be only possibilities for years and may be so for some time. Three state-owned sites are being evaluated, two prisons and one college: MCI-Norfolk, MCI-Shirley, and UMass-Amherst’s wastewater treatment plant (Clean Energy Results 2013). UMass Amherst will be accepting sludge, in addition to food waste (Slater, 2014). Deer Island is planning a food waste codigestion pilot in the next year. Dartmouth and Bourne are planning to add anaerobic digestion to their landfill gas facilities. Hamilton is planning for the first standalone anaerobic digestion facility on their closed landfill. The Stop ‘n’ Shop distribution center in Freetown is planning to develop an anaerobic digester to deal with their own food waste. Additionally, Ayer, Brockton, Plymouth, Barnstable, and Easthampton are conducting feasibility studies (Massachusetts Executive Office of Energy and Environmental Affairs, Anaerobic Digestion at Massachusetts Wastewater Treatment Plants).

Outside of Massachusetts, Bridgeport, Connecticut’s wastewater treatment plant is developing AD/CHP to codigest food waste (Anaergia to Generate Renewable Energy for the Bridgeport Wastewater Treatment Plant, 2013), and a standalone facility in Johnstown, Rhode Island is in the planning stages.

GIS ANALYSIS

Potential sites in Massachusetts for future AD/CHP facilities were selected through GIS analysis. Five potential types of locations were identified: wastewater treatment plants, food manufacturing facilities, cattle/pig farms, and landfills (both closed/inactive and landfill gas). The first three show potential because a large portion of the necessary feedstock is already on site, and the last one because its land use is appropriate for development of an industrial facility, and in the case of landfill gas, generation equipment already exists. For municipalities interested in developing their own AD/CHP facilities, municipal wastewater treatment plants and landfills are the most relevant, since they are generally on municipally owned land. The suitability of these sites was analyzed based on three major factors: competing facilities, sources of food waste, and the impact of traffic on nearby residents.

To avoid overlap with the collection areas of existing AD facilities, a series of 10, 20-, 30-, and 30-plus-mile rings were calculated around such facilities and assigned increasing values. Food waste is one of the more transportable feedstocks, because its relatively high energy content offsets the energy used to transport it. However, the maximum efficient distance to transport it is still only 25 to 30 miles. Only three of the existing facilities are currently codigesting food waste, but since it is much easier to retrofit an existing AD facility to codigest food waste and/or generate energy than it is to build an entirely new facility, this future potential should be considered when siting new facilities.

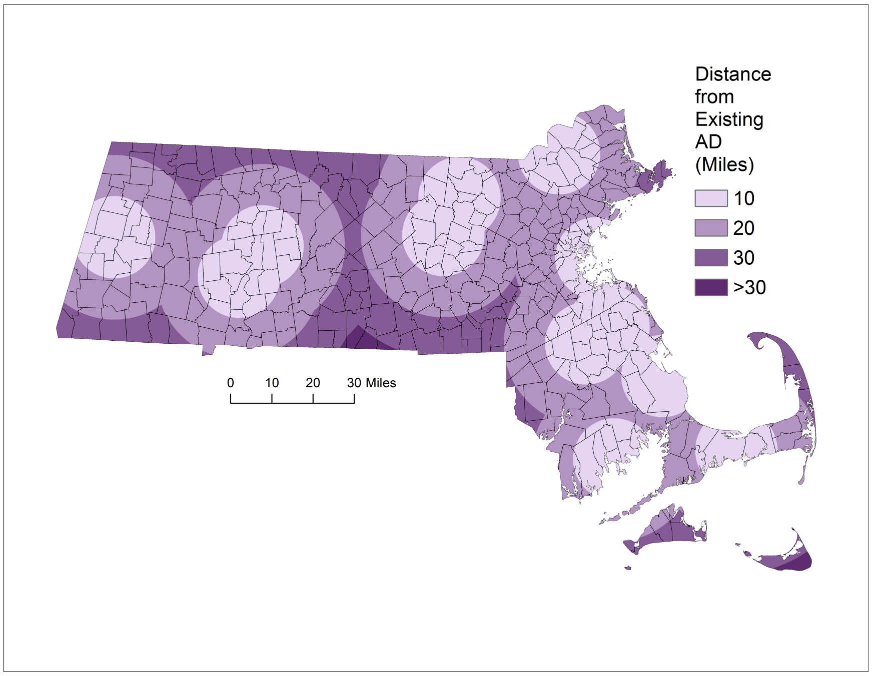

Figure 5: Distance from Existing AD

In order for a facility to gather a significant amount of food waste from its surroundings, it should be near entities that will be affected by the food waste ban. Again, a series of 10-, 20-, 30-, and 30-plus-mile rings were calculated around entities that generate more than a ton of food waste per week and assigned decreasing values.

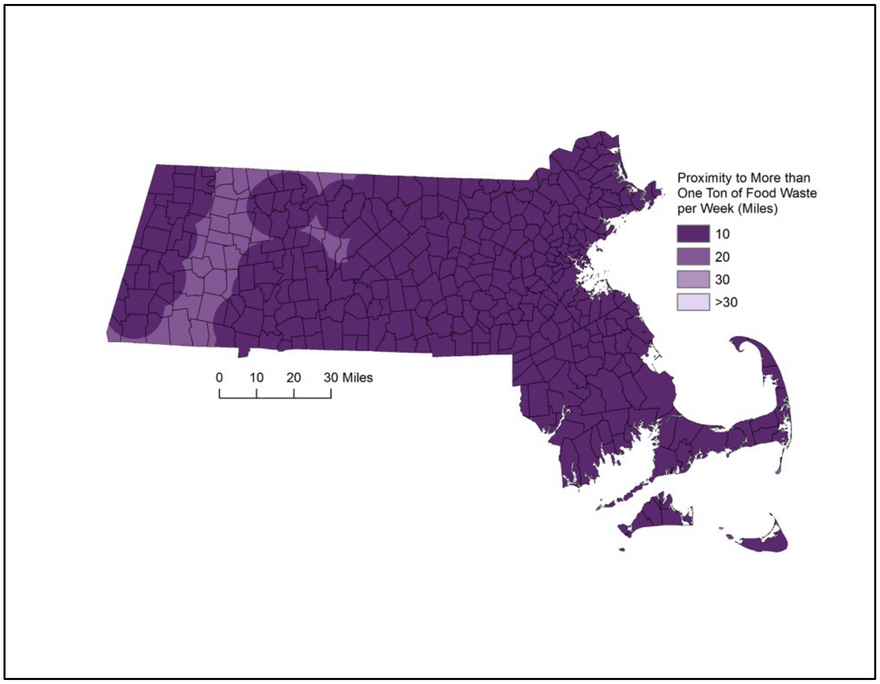

Figure 6: Distance from Food Waste Generators

Since a major concern of nearby residents to a planned AD/CHP facility is the number of trucks delivering feedstock to the site, traffic to the facility should remain off minor roads as much as possible. Major roads (defined as limited access highways, multi-lane highways, other numbered routes, and arterials and collectors by MassDOT) were selected, and a series of quarter-mile, half-mile, mile, and mile-plus rings were calculated around them and assigned decreasing values.

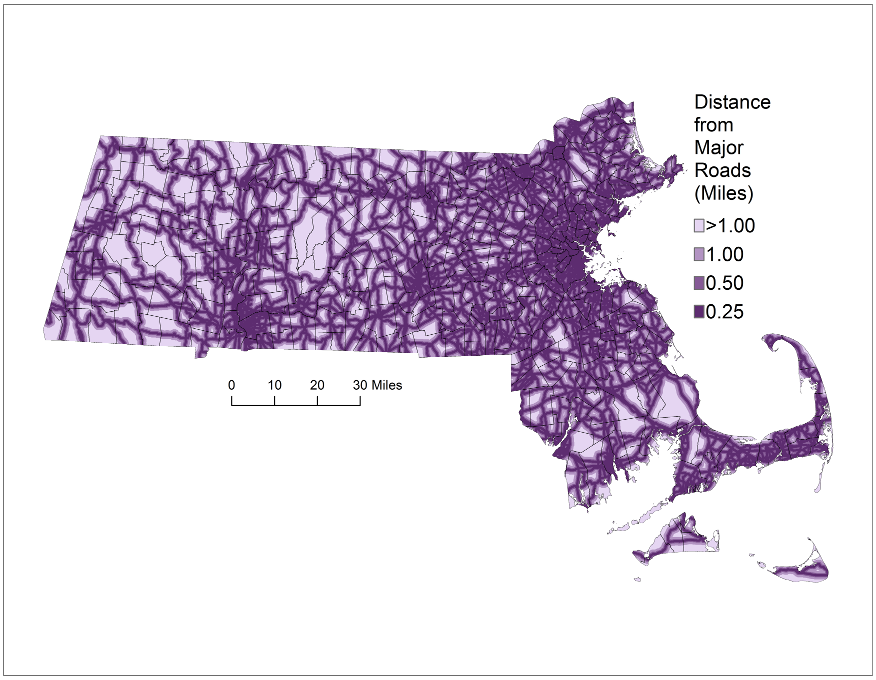

Figure 7: Distance from Major Roads

The three rasters were combined, weighting all three factors equally. The final ratings were transferred to the wastewater treatment plant and landfill sites.

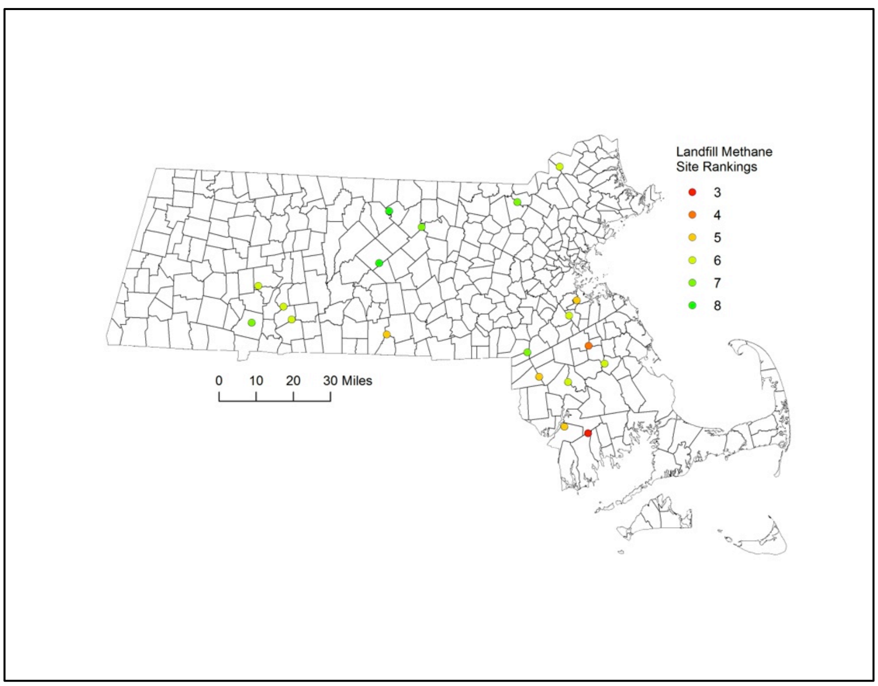

Figure 8: Landfill Methane Site Rankings

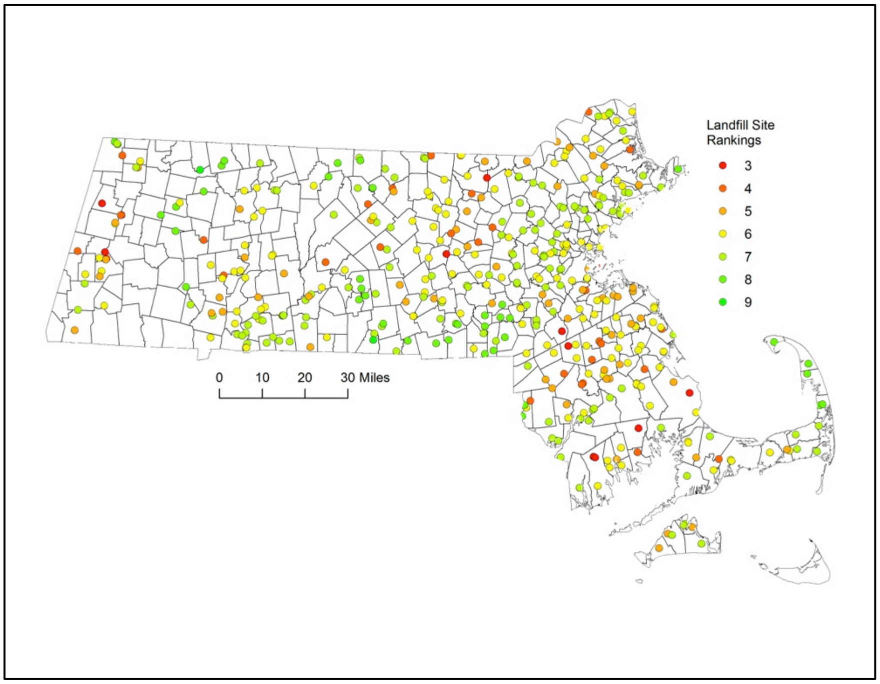

Figure 9: Landfill Site Rankings

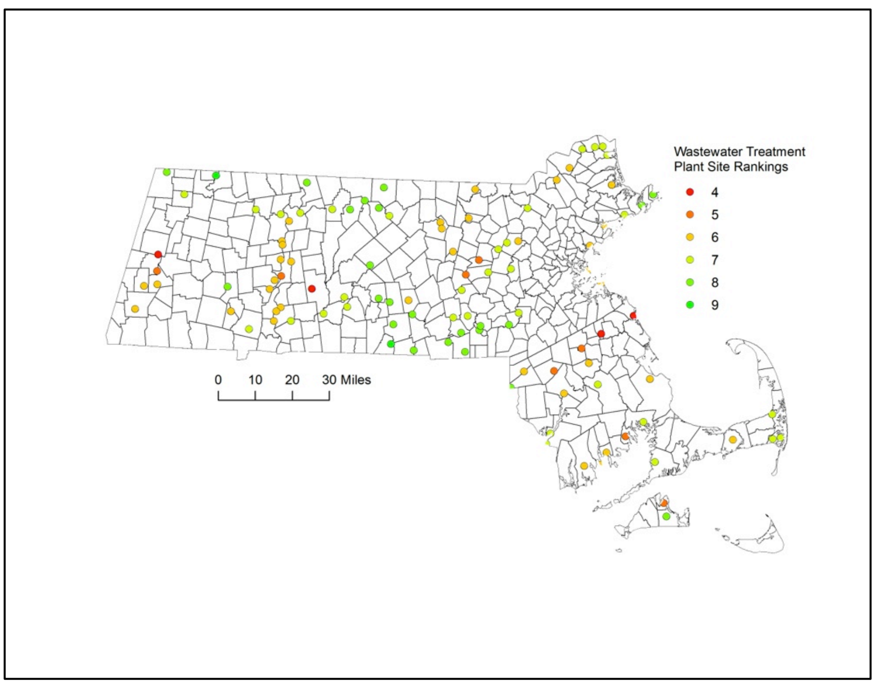

Figure 10: Wastewater Treatment Plant Site Rankings

RESULTS

Of the 530 original sites, most of the best choices for new AD/CHP facilities were found in south-central Massachusetts, north-central Massachusetts, the North Shore, and just outside the I-95 ring around Boston. The sites with the highest rankings were the Adams Wastewater Treatment Plant, Southbridge Wastewater Treatment Facility, Heath Landfill, Gardner Sanitary Landfill Methane Project, and Barre Landfill Methane Project. The second highest rankings included 32 landfills and 20 wastewater treatment plants. See Appendix B for a full list of the highest-ranked sites.

LIMITATIONS

A complete, up-to-date list of publicly owned wastewater treatment plants is difficult to find. MassDEP's list of Graded Wastewater Treatment Plants by Town was originally used; however, even reducing that list to just municipal facilities resulted in 337 facilities, many of which were no longer in operation or seemed to belong to businesses. Instead, MWPCA's list of municipal facilities was used, the same list referenced by MassDEP in its writing on the subject. However, there are only 118 facilities in this list, rather than the 133 wastewater treatment plants that MassDEP quotes, so there are still data quality issues. There does not seem to be a complete, publicly available list of municipal wastewater treatment plants. Going forward, MassDEP should be consulted to find a more accurate, complete list.

For this project, proximity to food waste was calculated simply, according to a site's distance to large food waste generators. However, to more accurately estimate the amount of food waste available, the amount of food waste estimated to be generated by each entity would be factored in.

The method used to calculate distance from major roads was essentially as-the-crow-flies. More useful would be finding the closest major road by following the road network. Further, finding the number of residential parcels along the minor roads connecting the facility to major roads would give a more accurate estimation of traffic impact on local residents.

Other considerations for future projects would be total availability of various feedstocks, including wastewater sludge and manure, not just food waste. Distance from residential parcels, wetlands, and other protected areas are all factors that should be considered, as well.

POLICY EFFECTS

States can encourage the development of anaerobic digestion by offering direct financial or technical assistance and removing regulatory barriers. Grants encourage cash-strapped municipalities to invest in their infrastructure and take advantage of technologies that they might not otherwise consider. Technical assistance helps busy municipal officials who may not have experience with this topic get up to speed. The food waste ban will make more feedstock available for digestion, and making non-farm AD/CHP facilities eligible for net metering guarantees a revenue stream. Simplifying the site assignment process for certain food-recycling facilities also eases the process. A delay in some of these favorable policy decisions in Massachusetts has led to uncertainty in the market, and even been a factor in plans for AD/CHP facilities being abandoned.

Municipalities can encourage AD/CHP development by identifying municipal land that would be appropriate for a facility. They may already have infrastructure in place, such as a wastewater treatment plant or a landfill gas facility, that would make development easier. They can also contribute feedstock by sending municipal or residential food waste to the facility. They can contribute financially by offering lower-cost financing with municipal bonds and/or purchasing power from the facility (Kilbourn, 2014). They are also uniquely placed to conduct public education and outreach (Slater, 2014).

CHAPTER FOUR: CASE STUDIES

To explore the Massachusetts context in depth, interviews were conducted to add to the available literature (see Appendix A). Case studies are presented for multiple facilities. Three wastewater treatment plants are explored that have AD/CHP but are not yet codigesting food waste: Deer Island, Pittsfield, and Fairhaven, in descending order of size. Also, two small wastewater treatment plants are shown that have AD but not CHP or codigestion: Rockland and Clinton. Two communities are examined that have considered landfill AD/CHP projects to accept food waste. One, Lexington, has abandoned the project in the face of negative public reaction; the other, Hamilton, is moving forward with an RFP for a developer. Lastly, a farm AD/CHP codigestion project is provided for comparison.

Facility	**Avg Flow (MGD)**	**AD Added (Year)**	**Electricity Capacity (kW)**	**Digestate Disposal**
Deer Island Wastewater Treatment Plant	365	1995	52,000	Pelletized Fertilizer
Pittsfield	13	1963	195	Incinerator (CT)
Fairhaven	2.7	2012	174	Incinerator (RI)
Clinton	3	1992	N/A	Landfill (MWRA)
Rockland	2.5	1982	N/A	Incinerator (RI)
Hamilton Landfill	N/A	N/A	N/A	N/A
Lexington Landfill	N/A	N/A	N/A	N/A
Barstow's Longview Farm	0.012	2013	300	Liquid Fertilizer

Figure 11: Case Studies

DEER ISLAND WASTEWATER TREATMENT PLANT

The Deer Island Wastewater Treatment Plant serves 43 communities in the greater Boston area. Processing an average of 365 million gallons of sewage per day (MGD), with a peak flow of 1,270 MGD, it is the second largest wastewater facility in the U.S. (O'Brien and Patneaude, 2014). It was originally built in 1890. The new primary plant was built in 1968 and renovated in 1995 and 2001. The wastewater treatment plant occupies about 150 acres of the 210-acre property. The rest is used as a public park (Duest, 2014). Benefits of AD/CHP for the facility include sludge reduction, fertilizer sales, lower-cost renewable energy, and resiliency.

Figure 12: Deer Island Wastewater Treatment Plant

ANAEROBIC DIGESTION

Deer Island has 12 egg-shaped digesters that were built between 1995 and 1998, financed by bonds, as well as federal and state assistance (Wong, 2011). The egg-shaped digesters are a space-saving measure, since they can occupy a smaller footprint for their height (10 stories) than other designs (O'Brien and Patneaude, 2014; Duest, 2014). Each digester has a capacity of 3 million gallons (Wong, 2011). Odor control is handled by scrubbers and carbon filters (O'Brien and Patneaude, 2014).

COMBINED HEAT AND POWER

Deer Island uses the biogas produced to maintain the temperatures of the digesters, heat the facility, and generate electricity with two 26 MW steam turbines. The biogas provides for 97% of the facility's thermal and 17.5% of its electrical demands, saving it $15 million in fuel oil costs and $2.5 million in electricity costs per year (O'Brien and Patneaude, 2014; Massachusetts Executive Office of Energy and Environmental Affairs, Wastewater and anaerobic digestion case studies; Massachusetts Executive Office of Energy and Environmental Affairs, Biogas Production, 2013). It also receives $1 million from sale of renewable energy credits (RECs) (Massachusetts Executive Office of Energy and Environmental Affairs, Biogas Production, 2013). About 98% of the biogas is used. The rest is flared when the cogeneration system has to be offline for maintenance (O'Brien and Patneaude, 2014).

Deer Island's 153,600 MWh per year represents three quarters of the MWRA's electricity use. Between AD/CHP, wind, and solar, 25% of the facility's electricity and 50% of its total energy use is generated on site. Two wind turbines have capacities of 600 kW and 100 kW each, and two solar PV arrays together have a capacity of 3.5 kW. A push to increase efficiency by 15% over three years has reduced the facility's electricity demand, with variable frequency drives, lighting retrofits, and process improvements, leading to 9,000 MWh/year saved. A major benefit of all of these energy improvements is resiliency. The facility has one cable to the mainland for electricity, and if the grid supply is interrupted, onsite energy generation ensures continuity of service (O'Brien and Patneaude, 2014).

DIGESTATE DISPOSAL

Digestate is sent by pipeline to a private pelletizing plant in Quincy, where it is dewatered, further purified, and turned into pathogen-free fertilizer, sold as Bay State Fertilizer (O'Brien and Patneaude, 2014; Massachusetts Executive Office of Energy and Environmental Affairs, Wastewater and anaerobic digestion case studies). It is offered free to member municipalities. The pellets are also sometimes bought for use in cement kilns, because it reduces their NOx emissions and the micronutrients in the pellets are beneficial for the cement (O'Brien and Patneaude, 2014).

Deer Island pays 12.7% of its total operating costs for sludge disposal, around $15 million per year (O'Brien and Patneaude, 2014). The plant is seeing the most significant cost savings from anaerobic digestion due to sludge reduction. Anaerobic digestion currently reduces the sludge by 55%, to 105 tons per day. At $350 per ton for disposal, that's a savings of $36,750 per day (Wong, 2011).

Wastewater treatment plant sludge is a class A biosolid, so it does add expense to purify it for use as fertilizer. An onsite pelletizing plant would be able to use the biogas for dewatering, as the Greater Lawrence Sanitary District does, but Deer Island's space constraints would make that difficult (Duest, 2014; O'Brien and Patneaude, 2014).

FOOD WASTE CODIGESTION

Deer Island is exploring adding food waste to its digesters. The facility is currently only using 8 of its 12 digesters. It could not expand to fill all 12, because some reserve capacity is necessary for redundancy. A pilot project in a single digester was originally planned to start in June 2014, with Waste Management trucking in the food waste. If the pilot testing were successful after 6-7 months, it would expand to a second digester and bring all the food waste in by barge (O'Brien and Patneaude, 2014). However, complaints from local residents about the anticipated truck traffic (nine trucks per day, five days per week), along with intervention by the Speaker of the Massachusetts House of Representatives, have put the pilot on hold until barge transportation is ready. It is now expected that the project will begin in the fall of 2014 (Duest, 2014).

Waste Management is developing a facility on the waterfront in Charlestown for separating, screening, and blending the food waste before transporting it by barge. Other facilities do the preprocessing onsite, but Deer Island cannot afford the space. Although it will be preprocessed offsite, Deer Island will also be grinding the food waste again on site to ensure the food particles are small enough (Duest, 2014). Receiving tanks for the food waste are currently being added to the facility, as well as additional motors, pumps, and grinders. Transporting food waste by truck or barge is more efficient than simply using garbage disposals to add it to the sewer system, because so much costly processing is done to wastewater before it reaches the digesters that much of the energy content is lost. MWRA has stated that residents with no option to compost their own food waste or have it collected separately are encouraged to use their garbage disposals, but commercial enterprises are not, since their higher volume would overwhelm the system and lead to clogs (O'Brien and Patneaude, 2014).

Bench-scale tests done in four-liter containers by the University of Massachusetts-Amherst helped Deer Island decide what ratio of wastewater to food waste to use. The original plan called for an 80/20 sludge to food ratio. However, up to 50% food waste led to higher methane production, added consistency to the process, and increased volatile solids destruction, which was just 42% for wastewater alone, and 88-90% with food waste. Therefore, food waste for the pilot has been increased to 40%. The increased solids destruction means that the addition of food waste will likely not increase the amount of sludge sent for pelletization, and may even decrease it. Interestingly, 100% food waste failed within 22 days, because of a lack of micronutrients and higher acidity (O'Brien and Patneaude, 2014).

Potentially higher nitrogen content in the water separated from the digestate may put the plant over its nitrogen limits, which it is at 95% of currently. If this is the case, extra equipment to remove the nitrogen from the discharge would be necessary (Duest, 2014).

With full-scale codigestion, all the facility's heating demand could be met with AD/CHP, as well as 45% of its electricity. In order to use the extra biogas efficiently, Deer Island may switch to a top-cycle CHP system. Its system is currently bottom cycle, in which heat is used first before electricity is generated. This results in an 80% efficient conversion to heat, but only 9% efficient conversion to electricity. A top-cycle system makes electricity first and uses the exhaust from the gas turbine for heating, resulting in an efficiency of 40% for electricity and 40% for heat. The plant is considering converting to top cycle in the future, regardless of the outcome of the food waste pilot; however, there are no immediate plans (Duest, 2014).

At full scale, Deer Island could take 1/3 of the statewide goal of diverting 350,000 tons of food waste per year from landfills and incinerators (O'Brien and Patneaude, 2014). With a capacity of anywhere from 250 tons per day (pilot) to 500 tons per day (full scale), it could be the lowest-cost option in the region, and could consume all the food waste within the route 128 circle. Because of this competition, it may be difficult for another facility in the area to secure a financing partner, so developers are considering facilities outside of the route 128 circle (Snellings, 2014).

FUNDING

Funding for the addition of a steam turbine for CHP was a combination of renewable energy grants from the Massachusetts Technology Center (MTC), capacity payments through the

Independent Systems Operator of New England (ISO-NE) Load Response Program, and the Massachusetts State Revolving Fund Program. Assistance was also provided by the Northeast Combined Heat and Power Application Center and NSTAR (Massachusetts Executive Office of Energy and Environmental Affairs, Biogas Production, 2013). Funding for bench-scale tests was provided by MassCEC, and funding for the pilot project will be provided by MassCEC and MassDEP (Duest, 2014).

PITTSFIELD WASTEWATER TREATMENT PLANT

In addition to Pittsfield, the Pittsfield Wastewater Treatment Plant services Dalton, Hinsdale, and some of Lenox (Shaw, 2014). Its average flow is 13 MGD (Massachusetts Executive Office of Energy and Environmental Affairs, Biogas Production, 2013), and its full capacity is 17 MGD. (Massachusetts Executive Office of Energy and Environmental Affairs, Anaerobic digestion at Massachusetts wastewater treatment plants). The benefits it sees from AD/CHP include reduced sludge volume, reduced vectors (pests), and resiliency. Since the plant is in a relatively rural part of the state, it loses power from the grid once or twice per year, and onsite electricity generation helps to prevent downtime (Shaw, 2014).

Figure 13: Pittsfield Wastewater Treatment Plant

ANAEROBIC DIGESTION

Pittsfield's anaerobic digesters were built in 1963, but rehabilitated in 1997 and 2004. The town almost decommissioned the digesters in the 1990s, because the covers needed to be replaced, and their cost was $1 million each (Shaw, 2014).

The digesters do not require much attention when they are functioning properly. However, in the past year operators have had issues with them that have reduced the amount of biogas produced, so the full benefits of CHP have not been seen yet. This was due to a series of issues. The gas compressor that does the mixing was down, and the sludge was not being mixed properly. Therefore, the digesters were not producing as much biogas, so the boilers were offline. The plant had also been having problems with the headworks, which meant that it was sending organics straight to the digesters, and the solids gummed up the works. The digesters needed to be shut down in order to be cleaned, and restarting them in the middle of the winter proved to be difficult. However, it's anticipated that warmer temperatures will get them running to full capacity. There are no plans to codigest food waste in the immediate future (Shaw, 2014).

COMBINED HEAT AND POWER

Historically, biogas has been used to generate heat to maintain digester temperatures (Massachusetts Executive Office of Energy and Environmental Affairs, Biogas Production, 2013). However, from 1963 to the early 1990s the plant had gas generators that ran full time. Then electricity got cheaper in Massachusetts and air regulations became more stringent, so it cost less to purchase electricity from the grid than generate it onsite (Shaw, 2014).

CHP was one of three projects identified by DOER- and WMECO-sponsored energy audits to reduce electricity use and generate renewable energy. These included energy-efficient aerators, solar PV, and CHP. The old mechanical aerator was replaced with a diffused air system with high efficiency turbo blowers, which are 15-20% more efficient than conventional blowers (Fontaine, 2009). This is estimated to save 919 kWh per year (Kulikausas). A solar PV array made up of five acres of ground-mounted panels that produce 1.5 MWh/year was also added. This provides for 35% of the plant's electrical demand and saves the plant $20,000/month (Kulikauskas; Shaw, 2014). For CHP, Kleinfelder recommended automating the digester mixing systems and increasing the sludge heat-exchanger capacity, adding three 65 kW microturbines and a gas conditioning system to remove contaminants, and using recoverable heat for the hot water loop. There is space in the building to add a fourth microturbine if the plant decides to expand. This is projected to generate 35% of the facility's energy needs (Fontaine, 2009). Estimated annual electricity savings are $206,000 (Kleinfelder), with an additional $45,000 per year in RECs (Shaw, 2014). Potential payback for the CHP portion of the project is estimated to be 5-8 years (Kleinfelder). Between these three projects, the plant will be nearly self-sufficient in energy use: grid demand will be reduced by 90% (Fontaine, 2009), leaving just 455 kWh/year of electrical demand from the grid (Kulikauskas).

The original design called for a distribution panel subfed from the main switchboard to run the CHP system. However, this separate CHP panel did not work well, so the plant is replacing their main switchboard with one that will also run the CHP system (Fontaine, 2009). Until the switchboard replacement is finished, the CHP system will be offline (Shaw, 2014).

From April through October, the biogas will be used more for electricity than heat. The digesters produce 60,000-80,000 cubic feet of gas per day average, with a maximum of 120,000 cubic feet. From December to February, supplemental heat is needed to maintain the digester temperatures. During this time, one boiler runs on biogas and one on fuel oil, costing the facility $100,000/year (Shaw, 2014).

DIGESTATE DISPOSAL

Pittsfield's anaerobic digesters reduce sludge volume by 20%, saving the plant a significant amount of money, since it pays $400,000/year in sludge removal. The contract for digestate disposal generally lasts for one year, and depending on price it goes to either a landfill or an incinerator. It is currently hauled to a Synagro facility in Connecticut. Because of heavy metals and PCBs in the sludge (the latter due to a nearby GE factory), the digestate cannot be used as fertilizer without considerable expense (Shaw, 2014).

FUNDING

Pittsfield received American Recovery and Reinvestment Act (ARRA) funding for the package of energy projects that included CHP, solar PV, and an efficient air handling unit. (Kulikauskas; Shaw, 2014). The CHP project alone cost $2.1 million (Wong, 2011). It also received capacity payments through the Independent Systems Operator of New England (ISO -NE) Load Response Program and assistance from the Northeast Combined Heat and Power (CHP) Application Center and its utility, WMECO (Massachusetts Executive Office of Energy and Environmental Affairs, Biogas Production, 2013). Pittsfield received a MassCEC grant for the feasibility study, as well as grants through the Clean Water State Revolving Fund (Wong, 2011).

FAIRHAVEN WASTEWATER TREATMENT PLANT

The Fairhaven Wastewater Treatment Plant was built in 1969. Its average flow is 2.7 MGD, and its capacity is 5 MGD (Wong, 2011). The major benefit of anaerobic digestion is the reduction in sludge volume. The biogas all goes into heating the digesters (as well as the building that houses their equipment) and powering the anaerobic digestion system, so there’s been little extra financial benefit from the electricity generation (Schlick, 2014).

Figure 14: Fairhaven Wastewater Treatment Plant

ANAEROBIC DIGESTION

The Fairhaven Wastewater Treatment Plant has the most recently installed anaerobic digester, built in 2012 (Schlick, 2014). Primary sludge is fed directly to the digester without secondary treatment. The tanks were built in sections, so they can be built up to increase capacity, if needed (Schlick, 2014).

Fairhaven was plagued with problems during start-up, and operators had to be on call 24 hours a day at first. Superintendent Linda Schlick likened it to having two newborns. She even named the reactors Damien and Dolores. The 27-year-old plant is due for an upgrade soon, and merging the new anaerobic digestion/combined heat and power system with the older equipment proved difficult (Schlick, 2014). The designers, Brown and Caldwell, were somewhat involved during startup, but as problems cropped up Thomas Bienkiewicz from the MassDEP gave the plant much-needed technical assistance (Schlick, 2014; Slater, 2014).

The most obvious problem occurred when a pipe burst in the sludge feed system, and sludge was actually forced up through the ground. Because of the small amount of flow during the winter, air was getting trapped in the pipes. To fix this, they changed the feed systems from plunger pumps, a type of positive displacement pump, to continuous feed. Timers were also installed on the pumps. In another incident, sludge bubbled high enough to get inside the digester's gas output line. This prevented the operators from even flaring the gas, and it had to be released into the atmosphere. This was because the level of sludge was designed to be too close to the top of the tank, and excessive burping and foaming made it reach the output pipe. To prevent this from happening again, the sludge level was reduced 10-15%. There was also an issue with the integrity of the methane holding tank. It leaked, losing methane into the atmosphere (Schlick, 2014).

Methane leaks are particularly egregious from a climate change perspective, since methane is 21 times more potent a greenhouse gas than carbon dioxide, on a 100-year time scale.

Fairhaven is considering codigesting FOG, soda waste, or other SSO in the future, but is not interested in pretreating any food waste on site, because of potential issues with neighbors (Schlick, 2014). Adding food waste could increase the energy output, providing for as much as 73% of onsite energy use (Wong, 2011).

COMBINED HEAT AND POWER

To generate electricity, one 110 kW and one 64 kW reciprocating internal combustion engine were installed (Wong, 2011), as well as a new master control center. The electricity generation is remotely monitored by Kraft Generation. At the moment, the plant's combined heat and power is still in its infancy. The generator is up and down, using a mixture of methane and natural gas. Boiler backup was used for most of the winter, and natural gas is costing the plant about $4,000 per month. Only the smaller generator was run this past winter, but it is anticipated that biogas production will increase with warmer weather and the plant will be able to generate at full capacity. Electricity is considered a side benefit, because at the moment it is simply powering the anaerobic digestion system (Schlick, 2014).

FUNDING

The AD/CHP project was funded mostly by ARRA, which at the same time funded installation of solar panels and wind turbines on the property. The AD/CHP portion cost a total of $10 million, $8 million of which was ARRA funding and $2 million was provided the town. Unfortunately, the town had budgeted only $500,000 for the project, but fixing all of the problems that cropped up cost an additional $1.5 million. A grant from MassCEC paid for the feasibility study (Schlick, 2014).

DIGESTATE DISPOSAL

Liquid digetate is sent back to the headwaters of the wastewater treatment plant for purification, and dry digestate is disposed of by Synagro at an incinerator in Woonsocket, Rhode Island. Because of the difficulty in removing toxics such as heavy metals from the sludge, using it as fertilizer is considered too expensive. Fairhaven is getting a new discharge permit soon because of nitrogen content and colloidal solids of the liquid digestate, so they will be using a UV system for disinfection and possibly pretreating with ferric chloride. The liquid digestate is being stored for the moment. Sludge disposal costs are the primary benefit that Fairhaven is seeing, and they are anticipated to drop $100,000 per year (from $350,000 to $250,000). Because the digesters are not running at full capacity yet, since they went online in colder temperatures, Fairhaven is currently seeing just $50,000 in savings (Schlick, 2014).

PUBLIC REACTION

Public reaction to the anaerobic digestion facility has been almost nonexistent. Most public attention has been focused very negatively on the two wind turbines that were added to the site around the same time. The anaerobic digestion facility has not added any extra odor or noise to the plant, and the feasibility study helped with community acceptance (Schlick, 2014).

ROCKLAND WASTEWATER TREATMENT PLANT

Rockland's wastewater treatment plant was built in 1964. Its flow was 1 MGD. Now its average is 2.5 MGD, with an upper capacity of 3 MGD. United Water currently runs the plant with eight employees. United Water also operates wastewater treatment plants in Hull, Cohasset, East Providence, and Newport. Benefits of anaerobic digestion include reducing the sludge volume and using the biogas to heat the digesters (Loughlin and Kotouch, 2014).

Figure 15: Rockland Wastewater Treatment Plant

ANAEROBIC DIGESTION

Anaerobic digestion was added in 1982 because the flow increased when more of the town was added to the sewer system. The anaerobic digestion system is easy to operate when it's running; however, the digester has been down for the past three months. Rockland replaced the old mixing system with chopper pumps in February, to deal better with any solids in the system and to mix the sludge more thoroughly. Because of the difficulty in starting a digester in the winter months, it's currently mostly acting as a sludge thickener. Once the weather gets warmer its operation will improve. Methane production and sludge reduction had been reduced for years because of the old mixer, and the plant is anticipating much better results with the new mixer. Rockland is unlikely to codigest food waste unless a CHP system is added. It is also already near capacity. Interestingly, decades ago Rockland used to collect residential food waste and send it to pig farms, but it no longer does (Loughlin and Kotouch, 2014).

COMBINED HEAT AND POWER

Rockland does not have a CHP system. The biogas produced is used in dual boilers to heat the digesters, and the excess is flared (Wong, 2011; Massachusetts Executive Office of Energy and Environmental Affairs, Biogas Production, 2013). Combined heat and power is not generally considered cost effective at this size (Slater, 2014). Rockland has discussed CHP with representatives from Siemens and MassDEP, but it has not done a feasibility study on the issue. Rockland will not be pursuing CHP in the immediate future, because they're not in a position to spend that much money. They are anticipating a major upgrade when their new discharge permit is issued very soon, because the phosphorous and nitrogen limits will be more stringent. A bond will be necessary for the upgrade, and they are trying to keep it under $5 million. Capital improvements are extremely expensive. Simply replacing the mixing system cost more than $330,000. Rockland also does not have much space to expand its operations. They are bordered by wetlands and a residential area. Because of the residential abutters, hours of operation and noise might also be an issue, although there have not been complaints in the past (Loughlin and Kotouch, 2014).

DIGESTATE DISPOSAL

Digestate disposal is the plant's third largest expense ($170,000 per year), after labor and electricity ($700,000 per year). Because of the volume reduction, AD reduces the cost for sludge disposal considerably, and adding CHP would also offset electricity costs. Digestate is sent to the Woonsocket, Rhode Island incinerator. Contracts for waste disposal are usually two years long, but the most recent one is five years. The cost is $87/ton, including hauling (Loughlin and Kotouch, 2014).

CLINTON WASTEWATER TREATMENT PLANT

The Clinton Wastewater Treatment Plant serves the towns of Clinton and Lancaster. The MWRA owns and operates the plant but gets no revenue from Clinton and Lancaster to do so because of an early 1900s agreement when the land for the Wachusett Reservoir was flooded. In exchange for the land, Clinton and Lancaster were offered free water and sewer service in perpetuity (Duest, 2014). Its average flow is 2.4 MGD and its capacity is 3 MGD (Massachusetts Executive Office of Energy and Environmental Affairs, Biogas Production, 2013; Wong, 2011). Anaerobic digestion is beneficial primarily for reducing the volume of sludge and stabilizing it (Slater, 2014). The digestate is belt-pressed and sent to an MWRA-owned landfill (Duest, 2014).

COMBINED HEAT AND POWER

Clinton does not have a CHP system. All the biogas is used in a dual boiler to maintain the digester temperatures and heat the building in winter (Massachusetts Executive Office of Energy and Environmental Affairs, Biogas Production, 2013; Wong, 2011). The excess is flared (Duest, 2014). CHP is generally not considered cost effective at this size (Slater, 2014). When Clinton investigated adding microturbines, they decided that it would only be cost effective if food waste were also added to increase the flow. There are two digesters, and one has been out of service for a long time. At the moment the digesters require 80-90% of the biogas for heat during the winter, so there would not be much excess for electricity generation during those months.

The cost of the microturbines would also be an issue. MWRA requested funding for repairs to the plant just last month and expect that contract would take a year or two (Duest, 2014).

FOOD WASTE CODIGESTION

The MWRA is considering codigestion for Clinton, but they are waiting on the results of the Deer Island pilot study before investigating it further. The plant would need a receiving and feed-in facility, storage tanks, and additional pumps to add food waste, but there are no space constraints. However, the MWRA would require food waste to be preprocessed offsite. It would only make sense to add food waste if a CHP system were in place to take advantage of the increased biogas (Duest, 2014).

TOWN OF HAMILTON LANDFILL

The Town of Hamilton is considering a public-private partnership for an anaerobic digestion facility that accepts food waste on its closed Chebacco Road landfill. This would likely be the first standalone anaerobic digestion facility in Massachusetts. The facility would be located on 3-5 acres of the 12.7-acre landfill. The rest of the 50-acre parcel is wetlands. The landfill was active until 1983 (CDM Smith, 2012). About 7 acres are already capped, and the town is in the middle of capping the rest of it now. It expects to be finished by August 2014. A final site closure plan was approved in 2013 (Town of Hamilton, 2013).

Hamilton issued an RFP in December 2013 for a private developer to handle permitting, financing, design, construction, operation, and ownership (CDM Smith, 2012). Bids were originally due in March 2014, but the deadline was extended to June, because the town would also like the same developer to add a 1-2 MW solar array on 5-7 acres of the site (Hamilton Board of Health Minutes, 2013; Lombardo, 2014). A number of developers have expressed interest. Six came to the site walk, and two have come forward since then (Lombardo, 2014). Private firms have access to tax incentives that the town would not, so it would be more financially feasible for them. The town is assuming that a simple AD/CHP system will cost $5-8 million. Interconnection is a significant one-time cost, because electricity generators are responsible for the expense of connecting to the grid. In its economic analysis, the feasibility study assumes a $40/day tipping fee, $15/ton fee for digestate disposal (including hauling), and that 100 tons per day would result in 1 MW of electricity (CDM Smith, 2012). The development of the RFP was paid for by a $60,000 MassCEC grant, with a 5% town match. The RFP costs that much to develop because of its technical nature (Lombardo, 2014).

Hamilton would lease the land to a developer for a period of 20 years, with the possibility of two additional five-year renewals. The town would have the option to keep the buildings and equipment at the end of the lease; otherwise the developer would restore the site to its original state. Two gun clubs could continue to lease portions of the land for shooting ranges (although one could be relocated if necessary), and the DPW could continue to use an acre to compost leaf and yard waste (CDM Smith, 2012). In addition to the land lease, the developer may also come to a PILOT (payment in lieu of taxes) agreement with the town (Town of Hamilton, 2013).

Advantages of the site include direct access from route 128, with no homes in between, a local zoning overlay district that encourages commercial development, and a wooded buffer to residential areas. Water is available at the site, likely from the Manchester-by-the-Sea water treatment plant. Gas is not. The facility also lacks connections to the sewer system to handle wastewater, so that would have to be transported offsite. The most significant limitation for the site is foundation requirements to build on the landfill, such as piles or soil piers, which would need to go through 10-30 feet of landfill down to bedrock (CDM Smith, 2012).

COMBINED HEAT AND POWER

Since there is currently no facility using electricity onsite, the developer would make power purchase agreements with other entities. Hamilton would have the right of first refusal to purchase electricity. The Manchester-by-the-Sea water treatment plant is located across Chebacco Road and may potentially use some or all of the electricity generated (CDM Smith, 2012). It currently spends $100,000 per year on electricity (Hamilton Board of Health Minutes, 2013).

DIGESTATE DISPOSAL

Digestate would be managed at an offsite location, since there is room to site a facility that can accept up to 250 tons of food waste per day, but little space for handling digestate (CDM Smith, 2012). There would also be environmental concerns about composting digestate onsite, since the Town of Manchester's drinking water supply is nearby, and the site is surrounded by wetlands (Lombardo, 2014). Disposal of digestate would be a significant ongoing cost, so a nearby long-term partner would be necessary (CDM Smith, 2012).

PERMITTING

The site is currently zoned as a Commercial Overlay District, with residential zoning 750 feet away. The anaerobic digestion facility will be considered biotechnology, so a special permit with design review would be required from the planning board. The site is within a Groundwater Overlay Protection District, so a special permit would be required from the zoning board of appeals and a Notice of Intent would have to be filed under the Massachusetts Wetlands Protection Act (310 CMR 10.00). The town's Conservation bylaw, National Pollutant Discharge Elimination System (NPDES), and Air Quality Regulations (310 CMR 7.00) would also apply (Town of

Hamilton, 2013). The Massachusetts Environmental Policy Act (310 CMR 11.00) may apply if the facility accepts more than 150 tons per day (CDM Smith, 2012). The developer would have to file a post-closure use permit application with MassDEP (Town of Hamilton, 2013). According to the revised MassDEP rules, because the facility would accept more than 60 tons per day, it would require a general permit. The process would include a draft permit, a public comment period, a public hearing, and administrative appeal. There's a chance that the old site assignment for the landfill could be modified, depending on what its limitations currently are, but the old site assignment cannot be found. Any board of health reviews would likely include the Essex and Manchester-by-the-Sea boards of health because the town lines are nearby (CDM Smith, 2012).

PUBLIC REACTION

The idea of the anaerobic digestion facility first developed because of a recycling conference that selectmen attended and a dialogue with MassDEP. There has been no public pushback so far. People have generally been curious or neutral. They may even be hopeful because they believe it may improve their tax situation. There are few businesses in Hamilton, so the tax burden is entirely born by residents. Revenues from the land lease, the PILOT, the solar PPA, or food waste tipping fees from other towns could improve that. Surrounding towns seem cautiously supportive. Manchester in particular may purchase lower-cost power from the facility, and the facility may purchase water from Manchester, since their water supply is nearby (Lombardo, 2014). To ensure that there is little effect on residents, traffic will be restricted to the portion of the road leading to route 128, where there are no houses, and to the hours between 7 a.m. and 4 p.m. Plans will be required from the developer for feedstock supply and inspection; odor control; dust control; vector (pest) control; stormwater management; lighting; and safety and emergency contingency. A traffic study must also be completed (CDM Smith, 2012; Town of Hamilton, 2013).

FOOD WASTE CODIGESTION

The developer will be allowed to accept up to 200 tons per day or 50,000 tons per year of food waste. Based on MassDEP's organic waste study from 2012, the facility's wasteshed could include Hamilton, Danvers, Essex, Ipswich, Manchester-by-the-Sea, Gloucester, and Rockport, with an estimated 9,100 tons per year of commercially generated organics between them. Including Salem and Peabody adds another 6,100 tons per year. Minimum tonnage for the facility to be profitable is calculated to be 100 tons per day or 26,000 tons per year, so other sources would have to be pursued, such as businesses outside of that area or residential food waste collection. The developer may also want to build the facility in phases while the market is expanding (CDM Smith, 2012).

Hamilton has implemented curbside collection for residential food waste, which averages 3.2 tons per day or 300 tons per year. It is currently picked up by Hilz Hauling and sent to Brick End Farm in Ipswich with the town's yard waste to be composted (CDM Smith, 2012). Six months ago the town had already seen $100,000-$110,000 from direct savings on waste disposal and revenue from bag sales (Lombardo, 2014). Hamilton is requesting that the anaerobic digestion facility accept residential food waste at no cost to the town, with a limit of no more than 1,500 tons per year, not including leaf and yard waste. Residential food waste drop-off would also be allowed (CDM Smith, 2012).

TOWN OF LEXINGTON LANDFILL

The Town of Lexington seriously considered a public-private partnership to develop an anaerobic digestion facility at its own landfill, located between Hartwell Avenue and route 128. However, negative public reaction led to the town abandoning the plan. The landfill is on 26 acres of a 67.5-acre parcel; the rest is wetlands (Town of Lexington, 2013). The landfill has not been used since 1980 and has been officially closed under the Hazardous Waste Act with no cap required, covered with 10-15 feet of soil (Town of Lexington, 2013). It is currently used as a composting facility that takes in leaf and yard waste from Lexington, Arlington, and private landscapers and sells the resulting fertilizer to landscapers and gives it away to residents for free (Valente, 2014; CDM Smith, 2011). About 10,000 tons per year of yard waste is currently composted in windrows (CDM Smith, 2011). The site is also used for DPW storage and household hazardous waste collection, and as a shooting range for the police department (Town of Lexington, 2013).

There were two options listed in the draft RFP. Option 1 was a land lease of up to five acres for only an anaerobic digestion facility. Digestate would be managed at an offsite location. The town would continue to operate a yard waste composting operation on the rest of the site (nearly half the site). Option 2 involved a land lease of up to 12 acres for the anaerobic digestion facility and covered aerated static pile composting of combined digestate and yard waste. The lease would be for 20 years, with up to two additional five-year extensions. The town would have the option to keep the buildings and equipment at the end of the lease; otherwise the developer would have to return the site to its original state. The developer would be responsible for the permitting, financing, design, construction, operation, and ownership (Town of Lexington, 2013).

The facility would have accepted only food waste, a maximum of 250 tons per day (50,000 tons per year), and yard waste of 50,000 cubic yards per year. Although the town had no plans for residential food waste pickup, residential food waste drop off would continue to be allowed, up to 3,000 tons per year, as well as leaf and yard waste, at no extra cost to the town. 5,000 cubic yards per year of finished compost would have been made available for free to residents and the DPW. No manure or sludge would have been allowed (Town of Lexington, 2013). Advantages of the site included a compatible existing use, sufficient land area, separation from residential property, and nearby access to water and sewer utilities. There is also an electrical substation near the entrance to the site, as well as a gas transmission line (CDM Smith, 2011). However, the site does fall within a transportation management district, which would require additional traffic management controls or a mitigation fee. Estimated truck traffic for 50,000 tons per year of food waste, yard waste, and compost would have been 48 round trips per day on a six-days-per-week schedule (Town of Lexington, 2013).

To be cost effective, the facility would need to accept 40,000-50,000 tons per year of food waste, plus another 44,000-55,000 tons per year of yard waste. A term of 15 years or more would be necessary for the developer to recover its capital cost. The composting facility generates $400,000 per year gross revenue (Valente, 2014), or $90,000 net, so the town would need to recognize benefits of at least that much (CDM Smith, 2011). A facility could have generated enough power for 2,500-3,000 homes. Lexington received grants from MassDEP and MassCEC to develop the RFP, but had to return most of it because the RFP was never issued (Valente, 2014).

PERMITTING

The site is zoned for commercial manufacturing. The nearest residential district is 700 feet away. It is bordered by the Minuteman Commuter Bikeway. A special permit with site plan review would be required from the board of appeals. Because the site is in a planning development zoning district, commercial district rezoning for the site would also have to be approved at town meeting. A notice of intent would have to be filed under the Massachusetts Wetland Protection Act. Under the new regulations, a general permit would be required from MassDEP rather than a site assignment. The Massachusetts Environmental Policy Act (310 CMR 11.00) and Air Quality Regulations (310 CMR 7.00) would apply. Because Hanscom Air Force Base is nearby, FAA regulations may have also reduced the height of any buildings. A post-closure use permit would be required for any new activity. A permit would also likely be needed from the Conservation Commission. To ensure no adverse affects, the developer would have to have a plan for feedstock supply and inspection to avoid toxics in incoming organics, as well as an odor control system, dust control, noise control, vector (pest) control, stormwater management, lighting, safety and emergency contingency. The town would be notified within 24 hours of nuisance conditions, and the board of health would have the authority to undertake enforcement action. To prevent any potential nuisance, compost would be cured indoors for the first 30 days (Town of Lexington, 2013).

PUBLIC REACTION

The idea of the anaerobic digestion facility first developed because of a conference attended by selectmen. The landfill site was underutilized and this was seen as a way for it to generate extra revenue. However, an RFP for a developer was never issued, because there was active opposition from residents and one of the selectmen. While Hartwell Avenue is a commercial district, Bedford Street leading to Hartwell has residents. Their concerns included truck traffic, odor, noise, and vermin. Most of these were due to misperceptions about anaerobic digesters. One of the selectmen actually visited Jordan Farms to find that there was no smell and the generator was quiet. However, the truck traffic was a real issue, and the concerns of the local residents were seen to outweigh the benefits to the town as a whole. And since there is not currently a ban on residential food waste, there was no immediate need for the town to take action about it. Residents wondered why Lexington would do something that would benefit others (Valente, 2014).

It did not help that people thought there was an aura of secrecy around the RFP process. The town did not want to make the RFP public until it was issued, since it might give one company a competitive advantage over another. Meetings with the conservation commission, the board of health, and the energy committee were held in executive session, which meant they could not discuss it publicly. Discussions ensued for more than one and a half years, in which officials met with two firms, Harvest and Neo, as well as the town's engineering consultant, CDM Smith, to find out more about the technology. During that time, rumors and fears multiplied. There was no existing standalone food waste anaerobic digester in the state, so there was some risk seen in being first (Valente, 2014).

The Board of Health's reaction was mixed. Because new MassDEP regulations for food recycling facilities had not yet been issued, they thought that it should be permitted as a solid waste facility. The wait for MassDEP to issue the new regulations was particularly damaging. The conservation and energy committees were generally supportive, but not outspoken in their support. The planning board wanted to first have the zoning changed before issuing the RFP, which was unrealistic, because a site plan is required in order for the zoning to be changed, and that would not be solidified until after a developer was hired. Because the site was in a planning development district, commercial development rezoning would be necessary, which in Lexington needs to be taken to town meeting. There did not seem to be enough support for it to pass a vote at town meeting, so the matter was dropped. Now the town is looking at developing a solar array on the landfill instead. This would likely replace the compost facility for yard waste, which was a popular part of the recycling program (Valente, 2014).

The public reaction was unexpected, because Lexington has a reputation for being "green." It has some of the first LEED-certified buildings in the state and a very successful recycling program, with both conservatives and liberals supporting it. The town has tremendous public involvement, with 75 boards and committees. However, there was very little advocacy for this project, and the case was not made sufficiently to residents. The town manager recommends that other towns considering an anaerobic digestion facility have a more public process up front, with clearly articulated benefits for residents (Valente, 2014).

BARSTOW'S LONGVIEW FARM

On December 31, 2013, Barstow's Longview Farm became the third dairy farm in Massachusetts to add AD/CHP. The major reason for pursuing it was because the farm needed more fertilizer than the manure it was currently producing. By codigesting food waste with the manure, more liquid digestate is produced. Other benefits that the farm is seeing are electricity generation and methane reduction. Steven Barstow's uncle was the one who first pushed the idea as a way of diversifying their income streams. Barstow's already has a store/restaurant on site and offers farm tours (Barstow, 2014).

Figure 16: Barstow's Longview Farm

ANAEROBIC DIGESTION

The digester is fed with a mixture of 5,000 gallons per day of food waste and 7,000 gallons per day of manure (a total of 50.4 wet tons per day). The digestion reactor is 800,000 gallons, and it's always at capacity. It's mostly buried underground (17 feet), with just two feet aboveground, to help retain its heat. The food storage tanks are also mostly underground (12 feet) (Barstow, 2014).

The process has mostly been smooth, except for one issue that almost stopped the project before it ever came online. A feed-in pipe for the manure froze the day it was supposed to begin operation. Hay had been thrown over it for insulation, but that was not enough. Now they are using insulating tape. The anaerobic digester provides all the electricity for the farm. It also reduces the methane produced by the manure. The farm is large enough (more than 200 cows) that the government scrutinizes its environmental impact. It's also close to a river (Barstow, 2014).

COMBINED HEAT AND POWER

A 300 kW generator is used to turn the biogas into electricity. Currently they're generating all the electricity used by the farm, with savings of $2,000 per month, but in the future, if they are able to set up a PPA, they will be able to take in more food waste and replace their engine with a larger one. The thermal energy is being used to heat the farmhouse and barn, but there is still excess (Barstow, 2014).

DIGESTATE DISPOSAL

The digestate is stored in a 2 million gallon storage tank to be used as liquid fertilizer on the fields in the spring. This saves the farm $80,000/year (Barstow, 2014).

FOOD WASTE CODIGESTION

Casella hauls in food waste from places such as Agrimart and Kane's. In the future, Casella is planning on pretreating food waste on site, as well as operating the digester (Barstow, 2014).

PUBLIC REACTION

There have been almost no complaints from the neighbors. One approached them about the noise of the generator, so extra soundproofing will be added to the building that it's housed in. Since there is excess heat being generated, Barstow's is considering setting up some sort of district energy system with its neighbors, to both use the excess heat and generate goodwill (Barstow, 2014). Anaerobic digestion facilities in Scandanavia and Denmark often use excess heat for district heating (Zglobisz, 2010; Dagnall, 1995).

FUNDING

The facility cost $3.7 million to develop. An LLC was created, called BGreen Energy, in which Barstow's has 50% ownership, Casella has 30%, and energy consultant/founder Bill Jorgenson has 20%. The major barrier was funding. ARRA funding (a 1603 grant) was absolutely necessary. If that had fallen through, the project was unlikely to have gone forward. In order to receive it, the facility had to be operational by the end of the year, which was why they were thawing the frozen manure pipe on New Year's Eve (Barstow, 2014).

Originally, five farms had signed on to add anaerobic digestion under the name AGreen Energy. However, three farms have since dropped out. Jordan Farms is the other successful project. Its facility cost $5.5 million. It's higher tech and supposedly easier to operate. Its LLC, AGreen Energy, is 40% owned by Jordan Farms, 30% by Casella, 20% by Bill Jorgenson, and 10% by Barstow's (Barstow, 2014).

CONCLUSIONS

In examining a selection of facilities in Massachusetts that either are operating or have considered adding AD/CHP, we can see that in the long term the Greater Boston area will likely have an option for food waste disposal in Deer Island, although only its pilot project will be ready for the fall. Other AD/CHP facilities in the state are either in the pilot stage or not large enough to accept the amount of food waste that will be generated. The most likely candidates to fill the gap are wastewater treatment plants, because their sites seem easiest to develop. An air permit is generally the only necessary permit that they do not already have, and negative public reaction is unlikely. Unfortunately, there seems to be a lot of deferred maintenance and upgrades necessary for more stringent permits, which capital improvements for AD/CHP are competing with. These financial realities are a significant barrier to AD/CHP development.

CHAPTER FIVE: RECOMMENDATIONS

The technology for anaerobic digestion/combined heat and power has improved significantly over the past few decades, making it a much more attractive option for organics disposal. The main breakthroughs needed for it to become more common in the U.S. market are not technical in nature, but in the areas of administration, funding, and risk management (Zlobisz, 2010). Massachusetts municipalities interested in encouraging the development of anaerobic digestion in their communities can see significant benefits, including lower-cost food waste disposal and power. Public/private partnerships allow them to take advantage of private companies' existing experience with the technology, as well as tax incentives for renewable energy that they would otherwise not have access to; however, depending on the design, such partnerships may also limit access to grant opportunities that could make such facilities more economically feasible. For private companies, partnering with a municipality may reduce their risk considerably, give them access to lower-cost municipal bond financing, a dedicated feedstock in residential food waste and/or wastewater, the ability for the power to be used by an existing large customer, and perhaps even an expedited permitting process.

SITING

Different locations for AD/CHP facilities represent different costs and benefits for municipalities. Existing landfill gas facilities and wastewater treatment plants are likely the best opportunities for municipalities to develop AD/CHP; however, standalone facilities and farms also represent opportunities for municipalities that are interested in disposing of food waste in a sustainable manner or purchasing local renewable power. The chart below summarizes considerations based on facility type.

	Wastewater Treatment Plants	Landfills	Farms	Food Processing Facilities
Benefits				
Lower/More Stable Energy Costs	High	Low	Medium	High
Energy Security	High	Low	Medium	High
Lower-Cost Food Waste Disposal	High	High	Low	Low
Value of Digestate	Medium	High	High	Medium
Revenue from Tipping Fees	High	High	High	High
Reduced Sludge Volume	High	Low	Low	High
Odor Control	Low	Low	High	Low
Water Quality Protection	High	Low	High	Medium
Greenhouse Gas Emissions Reductions	High	High	High	High
Barriers				
Facility Size	Low	Medium	Medium	Medium
Feedstock Availability	Low	High	Low	Medium
Staffing	Medium	Medium	High	Medium
Permitting	Low	High	Medium	Medium
Public Reaction	Low	Low	Low	Medium
Digestate Disposal	High	Medium	Low	Medium
Cost	High	High	Medium	Medium

Figure 17: Consideration Priorities by Facility Type

Existing landfill gas facilities can lower the capital cost of anaerobic digestion development considerably. This is because the CHP equipment already exists on site, a preexisting industrial facility means that a negative public response is less likely, and the relevant permits have already been acquired.

Anaerobic digestion offers significant benefits for wastewater treatment plants in terms of reduced sludge volume and energy costs. However, space constraints, funding limitations, and public response may all affect plants' ability to add AD/CHP. Most wastewater facilities in Massachusetts are smaller than has been considered financially viable for AD/CHP on their own, but the addition of food waste to the mix can increase their methane production to the point that it is economically feasible.

Standalone AD/CHP facilities, especially those on closed landfills, are also an opportunity for municipalities. However, they have no on-site feedstock, so there is some long-term risk in contracting for outside sources, which may scare off private investors. This may also result in extra cost and negative public reaction to transporting the outside feedstock. On the other hand, they avoid the difficulty of having to merge newer technologies with older ones, potentially saving significant expenses. Municipalities interested in siting an AD/CHP facility on a closed landfill should also consider developing landfill gas capture at the same site.

Farms are a promising non-municipal model. While most dairy farms in Massachusetts are not large enough to support an anaerobic digester on their own, adding food waste as a feedstock makes them more viable. The advantage of on-site use of the digestate addresses one of the potential difficulties with anaerobic digestion; however, funding such a facility can be difficult for farmers by themselves. Municipalities that are not interested in developing their own facility should consider collecting residential and municipal food waste and making long-term contracts with a local farm for its disposal, offering a reliable feedstock. They could also purchase power or RECs directly from the farm.

GAPS IN SERVICES

MassDEP's Organics Study and Action Plan identified multiple barriers to reaching the state's goal of reducing food waste by 35% by 2020. They included lack of information on sources and amounts of food waste, lack of collection and of separate systems at food waste generators, insufficient collection services, insufficient processing capacity, lack of end markets for products, a regulatory environment that is unclear and considered cumbersome, and the need for a steady supply of feedstock (Massachusetts Department of Environmental Protection, 2014). Public education and outreach can also be a significant barrier, but it has not been given the attention by state officials that other, more technical, barriers have. The most serious continuing issues seem to be the lack of pretreatment services, digestate disposal, and public education and outreach.

FOOD WASTE PRETREATMENT

Most facilities in dense areas are not interested in dealing with food waste directly, but would rather pipe it in from tanker trucks. This makes it easier to get approval to add food waste to an AD/CHP facility, reduces the cost of dealing with it, and avoids any space constraints onsite. However standalone pretreatment facilities will likely be more difficult to site, due to their greater potential for nuisance and fewer direct benefits to the community. Also, transportation of the food waste first to the pretreatment facility and then to the AD/CHP facility adds extra cost and carbon emissions to the process. Although Waste Management is developing a pretreatment facility in Charlestown to support the Deer Island food waste pilot, there are currently no existing facilities in Massachusetts, and this lack will likely continue to be an issue statewide.

DIGESTATE DISPOSAL

Something that is often not considered in discussions about AD/CHP is what will be done with the digestate and how much that will cost. While it is true that digestate can be a usable product, either for direct application to fields, composting, fertilizer pellets, or cattle bedding, this can be expensive depending on the facility. Farms could have an on-site use for the digestate, but wastewater treatment plants and standalone facilities have no such use. Standalone facilities could potentially add the digestate to any composting already done on-site, to be sold as fertilizer. However, wastewater treatment plants in particular must be concerned with toxins in the digestate, so they often send it to landfills or incinerators. The process to purify wastewater digestate and turn it into pelletized fertilizer is costly, and the permits are strict. Statewide, there are just two facilities to pelletize digestate, developed by Deer Island and the Greater Lawrence Sanitary District. Any AD/CHP facility currently looking for an alternative to incineration or landfill will likely have to develop their own.

PUBLIC EDUCATION/OUTREACH

In order for a project to be successful, it is important to get buy-in from plant operators, local decision makers, and the community as a whole (Wong, 2011). However, there is a significant lack of understanding of AD/CHP by the general public. Some concerns, such as odor and pests, are due to misperceptions, while others, such as increased truck traffic, have merit. Benefits, such as a reduced tax burden, more sustainable long-term waste disposal, and renewable energy generation, are less obvious on an individual level and must be clearly articulated. For this reason, a public education and outreach campaign is a crucial part of AD/CHP development, preferably as early as possible, in order for information to get ahead of any rumors. A committed local champion, especially at the executive level (mayor or selectmen), can help highlight benefits across departments and throughout the community. Unfortunately, many public officials have little knowledge of AD/CHP themselves, so partnering with an outside entity such as a private consultant or a public agency is essential. Little funding has been made available for such outreach in the past; however, MassCEC is now recognizing its importance and requiring public outreach for projects that receive their grant funding (Barad, 2014).

INFORMATION SHARING

Because of AD/CHP's relatively limited adoption in Massachusetts, professional experience with it, especially by existing municipal staff, is limited. This can make municipalities uncomfortable pursuing it. Information-sharing between municipalities can alleviate this discomfort; however, there seems to be little of that taking place currently. MassCEC recently made an effort in that regard by hosting a roundtable discussion for its grantees. However, this only came about after the agency saw delays in the completion of feasibility studies and only included its grantees. Information sessions open to all would go a long way towards expanding understanding of AD/CHP and increasing its adoption. These could be done by state agencies, such as MassCEC or MassDEP, or regional ones, such as MAPC.

FEASIBILITY STUDIES

While an AD/CHP facility is a multi-million dollar capital cost, grants can reduce costs to a municipality dramatically. The ARRA funding that many wastewater treatment plants took advantage of is no longer available; however, other local, state, and federal incentives are, and more may be established in the future. Municipalities interested in AD/CHP should be ready to seize such opportunities as they arise. Grantmakers are generally looking for "shovel-ready" projects; therefore, having already completed a feasibility or fatal flaw analysis will put municipalities in a good position (Wong, 2011). Such an analysis may also identify other funding opportunities or models, as well as more benefits than expected, making the facility more feasible than expected. Feasibility studies can be expensive, but can be leveraged to save the municipality far more money in the future.

CONCLUSION

AD/CHP sits at the intersection of waste disposal and energy generation. This is an especially important area for municipalities to get involved with, because they and other government entities are the ones most interested in the public good and addressing the negative externalities of the private market. In this case, such externalities include food and wastewater sludge taking up dwindling space in landfills and emitting harmful greenhouse gases into the atmosphere as they break down, as well as the greenhouse gases and other pollutants emitted by generating energy from fossil fuels. Looked at on a strictly economic level for individual facilities, anaerobic digestion/combined heat and power facilities may only make financial sense at a certain size or location. However, taking into account the external costs we are all paying for waste disposal and fossil fuel use, it makes sense for government entities to invest money and employee time into the development of such facilities. Massachusetts has already recognized this by banning organics from large commercial entities in landfills and mandating an increasing percentage of renewable power. While private companies are unlikely to look past their own profit, public entities have a wider view and are entrusted with ensuring the public good. Developing anaerobic digestion/combined heat and power facilities is one way to do so, and a particularly relevant one in today's climate.

APPENDIX A: INTERVIEWS

ENTITY	NAME	DATE	METHOD
State Agencies			
Massachusetts Department of Environmental Protection, Wastewater Treatment	Alan Slater	3/12/14	In Person
Massachusetts Clean Energy Center	Amy Barad	3/13/14	In Person
RecycleWorks	Sean Pontani	3/31/14	In Person
Municipal Wastewater Treatment Plants with AD/CHP			
Pittsfield	Carl Shaw	3/31/14	In Person
Fairhaven	Linda Schlick	3/17/14	In Person
Rockland	John Loughlin & Rick Kotouch	4/1/14	In Person
Clinton & Deer Island (MWRA)	Dave Duest	4/3/14	Phone
Deer Island (MWRA)	Dan O'Brien & Kristen Patneaude	2/21/14	In Person
Farms with AD/CHP			
Barstow's Longview Farm	Steven Barstow	3/31/14	In Person
Private Developers			
Casella Organics	Jay Kilbourn	3/28/14	Phone
Harvest Power	Sam Snellings	3/24/14	Phone
Municipalities Considering AD/CHP			
Hamilton	Michael Lombardo	3/20/14	In Person
Municipalities Rejecting AD/CHP			
Lexington	Carl F. Valente	3/24/14	In Person

APPENDIX B: TOP-RANKED POTENTIAL SITES

Facility	Ranking
Heath Landfill	9
Monroe WWTP	9
Southbridge WWTP	9
Athol Landfill	8
Athol WWTP	8
Attleboro WWTP	8
Barre Landfill (Landfill Methane)	8
Barre WWTP	8
Bellingham Old Landfill	8
Blackstone Old Landfill	8
Brookfield Landfill	8
Buckland Landfill	8
Charles River PCD (WWTP)	8
Charlton Old Town Dump	8
Charlton WWTP	8
CJ Mabardy Demolition, Winchendon	8
Cole Field Landfill, Williamstown	8
Colrain Brush Landfill	8
Douglas Landfill	8
Douglas WWTP	8
East Brookfield Landfill	8
Eastham Landfill	8
Edgartown WWTP	8
Franklin Landfill	8
Gardner Landfill (Landfill Methane)	8
Gloucester WWTP	8
Holliston Union Street Dump	8
Hoosac WGD (WWTP)	8
Hopedale WWTP	8
Huntington WWTP	8
Medway Landfill	8
Milford Landfill	8
Milford WWTP (Hopedale)	8
MJ Murphy Landfill, Hopedale	8

Facility	Ranking
NA Nickerson Stump Landfill, Eastham	8
North Brookfield Landfill	8
North Brookfield Landfill	8
North Brookfield WWTP	8
Northbridge Landfill	8
Northbridge Redevelopment Corp (Landfill)	8
Northbridge WWTP	8
Northfield WPCF (WWTP)	8
Oxford-Rochdale SD WPCP (WWTP)	8
Plainfield Landfill	8
Provincetown Landfill	8
Rockport Landfill	8
Rockport WWTP	8
Royalston Landfill	8
Royalston WWTP	8
Seekonk Landfill	8
Seekonk Old Landfill	8
Slowinski Landfill Colrain	8
Spencer WWTP	8
Templeton WWTP	8
Texon Former Waste Disposal Site, Huntington	8
Truro Landfill	8
Uxbridge Landfill	8
Uxbridge WWTP	8
Webster Landfill	8
Webster WWTP	8
Wellfleet Landfill	8
Williamstown Landfill	8
Winchendon WPCF (WWTP)	8
Windsor Landfill	8
Worthington Landfill	8

Note: Rankings are based on GIS analysis discussed in Chapter Three.

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