Tapping the Energy Potential of Municipal Wastewater Treatment: Anaerobic Digestion and Combined Heat and Power in Massachusetts

Massachusetts Department of Environmental Protection

by

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Preface

With recognition of the nexus between energy and the environment and a revitalized effort to proactively seek opportunities to reduce green house gas emissions, MassDEP took a closer look at its regulated entities to identify opportunities to promote energy efficiency and renewable energy.

Wastewater treatment plants (WWTPs) along with drinking water facilities were considered good candidates due to the vast amount of energy involved. WWTPs range from small privately-owned facilities treating sanitary wastewater from a housing development to large regional facilities treating millions of gallons a day of sanitary and industrial wastewater. In cooperation with local and federal authorities, MassDEP regulates many types of wastewater treatment plants which often require significant energy to operate and can be responsible for a large percentage of a municipal's energy costs.

The Massachusetts Energy Management Pilot for Drinking Water and Wastewater Treatment Facilities was an opportunity for MassDEP and local strategic partners to guide facilities through an assessment of their current energy performance, conduct energy audits, and assess renewable energy generation potential. The results of this pilot included several recommendations, one of which was to explore biogas potential at publicly owned waste water treatment facilities.

Through assistance from the MassDEP Internship Program, research began by looking at biogas usage at WWTPs in Massachusetts. The synthesis of the research data and the development of this final report would not have been possible without the assistance of Shutsu Chai Wong, a graduate intern from Massachusetts Institute of Technology (MIT), whose hard work and dedication to this research was unmatched and outstanding.

Research for this report began in Massachusetts yet the limited case studies available soon led us to extend our research beyond the Massachusetts border. It is our hope that municipalities, waste water treatment operators, and others involved in the treatment of waste water will be able to use this research and the resources provided to further explore the potential of biogas as a viable renewable energy source for their facilities.

Allexe Law-Flood,
Commissioner's Office,
MassDEP

Introduction

Through a process called anaerobic digestion (AD), organic solids can be broken down to produce biogas, a methane rich byproduct that is usable for energy generation. When applied at municipal wastewater treatment facilities, an existing waste stream can be converted into renewable energy through a combined heat and power system (CHP). If additional organic waste streams are diverted to these facilities to supplement municipal wastewater solids, even greater efficiencies and energy potential can be attained for energy generation onsite and resale to the grid. Such a program leads to environmental benefits from methane capture, renewable energy generation, and organic waste volume reduction. Furthermore, facilities can reduce their operational costs associated with energy consumption and waste disposal while generating revenue from processing additional waste streams.

This paper establishes the merits and benefits of these technologies, the existing conditions at state wastewater treatment plants (WWTPs) and the potential for a renewable energy strategy that focuses on WWTPs as resource recovery centers.

Background

Wastewater treatment plants (WWTPs) present an untapped source of renewable energy. Within the millions of gallons of wastewater that pass through these plants in any given day are hundreds of tons of biosolids. When anaerobically digested, those biosolids generate biogas which can be anywhere from 60 to 70 percent methane. (Natural gas that is typically purchased from the grid for use on-site is methane.) If captured, that biogas can fuel an on-site combined heat and power generation system, thus, creating a renewable energy source. *In fact, contained within the wastewater is ten times more energy than is necessary to treat that water.*[1] As of June 2011, only six of 133 municipal WWTPs in Massachusetts utilize anaerobic digestion, and of those six, only three are using or in the process of installing a CHP system to generate renewable energy on-site.

In addition to the environmental benefit of renewable energy, on-site generation also has economic incentives. Where energy can be captured from existing byproducts such as sludge, less energy must be purchased from the grid and less sludge must be transported for processing off-site (either for land application, to a landfill or to another company for further processing). On-site energy generation also promotes energy independence and helps to insulate municipal plants from electricity and gas price fluctuations. At present, the cost of wastewater and water utilities are generally 30-60 percent of a city's energy bill[2], making it economically advantageous for municipalities to adopt these technologies to minimize the impact of these utilities on their limited budgets.

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[1] "Sustainable Treatment: Best Practices from Strass in Zillertal Wastewater Treatment Plant." Water Environment Research Foundation. March 2010.

[2] "Ensuring a Sustainable Future: An Energy Management Guidebook for Wastewater and Water Utilities." Office of Watewater Management of the U. S. Environmental Protection Agency with the Global Environment and Technology Foundation. January 2008.

Treating millions of gallons of wastewater containing biosolids, these Massachusetts' WWTPs are processing a potential fuel every day, and more often than not, that fuel simply passes through the plant and goes to landfill. This study aims to encourage the installation of systems that can harness that energy for productive use instead of allowing it to go to waste.

Wastewater Treatment and Anaerobic Digestion

The typical wastewater treatment process begins with the piping of water from the sewer system to the treatment plant. There, settling and thickening processes remove mud, grit and water, creating a dewatered sludge. That remaining sludge and water mixture is then treated to remove chemicals (some facilities may use advanced treatment processes) and is subsequently prepared for transportation to an off-site landfill, incinerator, or composter. Alternatively, that sludge can also be stabilized and prepared for soil amendment and land application.

If added, the process of AD would follow the settling and thickening steps and could serve as a sludge stabilization method. With AD, sludge is instead piped into digesters where, in the absence of oxygen and with constant mixing and heating, naturally occurring microorganisms break down waste solids, producing methane, carbon dioxide and several other trace gases in the process. Due to its high methane concentration of 60 to 70 percent,[3] that gas, often called biogas, can be captured and flared or productively used for energy generation. To harness the energy contained in biogas, the gas can be cleaned, compressed and burned in a boiler, generating heat for maintaining digester temperatures and on-site heating. In conjunction with a CHP system, the gas can also be used to produce electricity.

AD is not exclusive to WWTPs and can be used in agricultural settings, with industrial organic wastes, source separated organics, and for other pre- and post-consumer food wastes. AD has potential beyond the immediate application discussed here, and it is worth noting that the addition of food wastes, whether at a WWTP or at some other treatment facility, can increase the productivity of digestion because of the high organic concentrations. In fact, in Massachusetts, several dairy farms, also known as the Massachusetts Dairy Energy group, are collaborating to adopt the use of AD and CHP to manage manure and dairy processing wastes.[4] The group is awaiting approval from the Massachuetts' Department of Agricultural Resources to use the AD effluent as fertilizer.[5] Furthermore, at the Fairhaven, MA WWTP, the upcoming plant upgrades went so far as to consider the incorporation of solid food wastes into the wastewater stream in addition to fats, oils and grease (FOG). Unfortunately, the technology for pulping and slurrying post-consumer wastes is currently designed for much higher volumes and has yet to be scaled down; consequently, the cost of the equipment is currently

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[3] "Anaerobic Digestion." AgSTAR, an EPA Partnership Program. Web. <http://www.epa.gov/agstar/anaerobic/index.html>. Accessed February 2, 2011.

[4] More about the project on the Massachusetts Technology Collaborative website, including a copy of the feasibility report: http://www.masstech.org/project_detail.cfm?ProjSeq=901

[5] Meeting with Bureau of Waste Prevention. June 1, 2010.

prohibitive.[6] (The current size of the technology suggests that regional food waste solutions may be more economically viable at the moment.) Furthermore, the process of slurrying the food[7] is considered solid waste management and would require additional permitting and site reassignment. The WWTP was ultimately unable to consider the introduction of this new waste stream to their state-of-the-art wastewater treatment system.

Combined Heat and Power Systems and Anaerobic Digestion

The underlying concept of CHP systems is the use of a single fuel for the production of electricity and heat, where the waste heat from electricity generation is recovered for productive use.[8] When coupled with AD, biogas generated by the AD process fuels the CHP system. The types of CHP systems are varied and have different benefits and challenges associated with each one. The five types typically considered are: gas turbines, microturbines, steam turbines, reciprocating engines and fuel cells.[9] The use of Stirling engines has also emerged but is relatively new and untested. Additional detail regarding the CHP system types are in Appendix E.

Benefits of AD and CHP

While this study has alluded to many of the benefits of AD and CHP, a deeper discussion of each and its direct impact on WWTP operation are worth exploring in greater detail. The primary benefit of using AD is the production of biogas. As previously discussed, the methane content of biogas can be productively used in conjunction with one of many types of CHP systems to produce renewable energy through heat and electricity production. This process provides a whole host of secondary benefits for the WWTP and the environment. As many of the benefits listed above are also associated with some level of cost savings, the sum total savings is a significant contributor to the case for the adoption of AD and CHP.

One of the most noticeable benefits of using AD and CHP onsite at a WWTP is *the energy demand reduction* of the plant. By producing heat and electricity onsite using the wastewater that the plant already treats, net operation costs are reduced; the amount of energy that the plant must purchase from the grid is smaller, and thus, their energy bill is smaller. Reducing that reliance on offsite energy supplies insulates the plant from energy price fluctuations; Sheboygan, Wisconsin's energy prices

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[6] Personal Communication with Bill Fitzgerald from Fairhaven WWTP by Shutsu Wong. July 2, 2010.

[7] Food needs to be slurried before it can be fed to a digester for AD; food waste is not as processed as biosolids that have passed through the human body or agricultural animals. Wastes such as FOGs and dairy and beverage processing wastes are already in small enough particles for direct feeding, making them simpler for addition to digesters.

[8] "Basic Information." U. S. Environmental Protection Agency, Combined Heat and Power Partnership. Accessed June 6, 2010 from http://www.epa.gov/chp/basic/index.html.

[9] "Basic Information." U. S. Environmental Protection Agency, Combined Heat and Power Partnership. Accessed June 6, 2010 from http://www.epa.gov/chp/basic/index.html.

increased rose over 70 percent over six years, and its use of AD and CHP reduced the impact of those increases on the facility (see case study of Sheboygan, WI). In addition, since net operation costs are reduced, the ratepayer also experiences lower prices. In the Village of Essex Junction in Vermont, the annual energy usage was reduced by more than a third through the addition of a CHP system (see case study of Village of Essex Junction, VT).[10]

More specifically, AD and CHP together and AD alone can generate useful heat and electricity in several ways. In the case of the Clinton WWTP, a 3.0 million gallons per day (MGD) design flow facility in Massachusetts, biogas production from AD is fed into a dual boiler that produces heat to maintain digester gas temperatures.[11] In the winter time, that gas also heats buildings onsite. All of the digester gas is consumed through these two processes during the winter, and consequently, no CHP system is installed there. In larger systems where CHP is a viable option, additional electricity can be generated through digester gas to power other processes onsite.

Another benefit of AD is the *reduction of sludge volumes* that must be transported off-site to a landfill, for direct land application, for incineration or for further processing to produce products such as fertilizer. AD significantly reduces sludge volumes; at the Massachusetts Water Resource Authority (MWRA) treatment plant at Deer Island, total solids are reduced by 55 percent during the digestion process.[12] At $350 per dry ton and a production rate of 105 tons per day at Deer Island *after* AD, the savings are on the order of tens of thousands.[13] Granted that Deer Island is the largest plant in Massachusetts, the experience at this WWTP demonstrates that savings in sludge volume reduction alone can be significant. The costs of transporting the sludge as well as the tipping fees are reduced. Reduced volumes also has the potential to impact the amount of truck traffic through nearby communities, improving the relationship of these facilities with their neighbors. For Nashua, NH, that meant a reduction from 50 truckloads a week to 20 with the addition of AD to their WWTP (see case study of Nashua, NH).

Beyond the usefulness of this energy at the WWTP itself, distributed energy generation also has *benefits for the greater community*. WWTPs have also employed CHP systems in response to inconsistent power supplies and anticipated power outages or shortages. In Portland, Oregon, extended power outages in December of 1995 and February of 1996 motivated the Columbia Boulevard WWTP to install its 200kW fuel cell system; this system served as a secondary power supply, a backup system for essential

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[10] Eaton, Gillian, Jutras, James L. "Turning Methane into Money: Cost-Effective Methane Co-Generation Using Microturbines at a Small Wastewater Plant."

[11] Personal communication with John Riccio at Clinton WWTP by Shutsu Wong on June 15, 2010.

[12] Personal communication with David Duest, MWRA Deer Island WWTP manager, by Shutsu Wong on March 4, 2010.

[13] Personal communication with David Duest, MWRA Deer Island WWTP manager, by Shutsu Wong on March 4, 2010.

communications and control of remote facilities during power outages.[14] In New York City, anticipated power shortages in August 2000 for the summer of 2001 triggered a fast-track process for the siting, design and installation of eight fuel cell units.[15] In addition to insulating the plants from those shortages the following summer, reducing their demand on the grid also helped to insulate the city from the summertime shortages amidst record heat.[16] During the Northeast Blackout in August 2003 and following the terrorist attacks in September 2001, these plants helped to meet electricity demands again and stabilize the transmission system, further demonstrating their value to their community, city and state.[17]

The *environmental benefit,* which plants themselves may not be able to assess, arises from the diversion of methane for productive use. As the microorganisms are naturally occurring in wastewater, methane is also naturally produced in wastewater; instead of allowing that to escape into the environment, it is captured for reuse. Furthermore, the carbon dioxide emissions produced by power plants generating the electricity for use by WWTPs will also be reduced, as plants will purchase less energy from those sources. In addition, the emissions associated with sludge transport will also be diminished by the total volume reduction of sludge onsite prior to removal. Moreover, while AD may produce carbon dioxide as a byproduct, methane has been estimated to be 20 times more effective at trapping heat in the atmosphere than carbon dioxide.[18] Thus, the active capture and use of methane from the breakdown of organic materials is especially important as a part of any greenhouse gas emission reductions program and can play a significant role in limiting global warming. This same logic is the basis for methane capture in landfills which already occurs in Massachusetts, but comparatively, methane capture through AD is more controlled and effective and therefore more environmentally beneficial.[19]

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[14] "Columbia Boulevard Wastewater Treatment Plant: 320kW Fuel Cell and Microturbine Power Plants." CHP Case Studies in the Pacific Northwest, U. S. Department of Energy Energy Efficiency and Renewable Energy.

[15] "PowerNow! Small, Clean Plants." New York Power Authority. Web. July 7, 2010. <http://www.nypa.gov/wwwnypagov/wwwroot/facilities/powernow.htm>.

[16] "PowerNow! Small, Clean Plants." New York Power Authority. Web. July 7, 2010. <http://www.nypa.gov/wwwnypagov/wwwroot/facilities/powernow.htm>.

[17] "PowerNow! Small, Clean Plants." New York Power Authority. Web. July 7, 2010. <http://www.nypa.gov/wwwnypagov/wwwroot/facilities/powernow.htm>.

[18] "Climate Change: Methane." Environmental Protection Agency. Web. Accessed January 31, 2011. <http://www.epa.gov/outreach/>.

[19] Current discussions around landfill gas capture efficiency demonstrate that the lack of control over methane emissions and the capture of gas by other landfill materials reduce the energy capture potential. (See "Landfill Gas Collection System Efficiencies." MSW Management: The Journal for Municipal Solid Waste Professionals. July 1, 2008. Web. < http://www.mswmanagement.com/web-articles/landfill-gas-collection.aspx>. Accessed February 2, 2011.)

A History of Anaerobic Digestion and Combined Heat and Power in Massachusetts

While AD is not currently used extensively in Massachusetts, AD *was* used at MA WWTPs as early as the 1940s. In these early days of AD in MA, AD was mostly used as a waste stabilization process with primary treatment. When secondary treatment was introduced in the 1970s and 1980s because of the Clean Water Act, challenges began to emerge with existing AD systems. Process upsets resulted from different secondary sludge and supernatant characteristics and odor control became more difficult. Consequently, many facilities opted for different methods of sludge management such as composting, incineration and landfilling. These process upsets also led to a negative perception of AD for wastewater treatment, which is a barrier to adoption in the present day despite technological and process advances.

Despite the historical challenges, there has been renewed interest in AD because of its potential for energy recovery, greenhouse gas reduction, and diversion of organic wastes from landfills. In the last 3-5 years, interest has emerged from the Environmental Protection Agency (EPA) and the Department of Energy (DOE), and this renewed interest has led to new ideas, new initiatives and market growth for these technologies.

Thus, while the literature may still be lacking,[20] the technologies are maturing and the number of case studies from across the nation and around the globe demonstrating financial and environmental benefits and technical feasibility are growing. Even within the state of Massachusetts, success stories are emerging.

Status of WWTPs in Massachusetts & MA Case Studies

In Massachusetts, there are 133 WWTPS, and of those, only six WWTPs that are employing or are in the process of installing AD at their facilities. Of these six, three have or will have CHP systems to maximize the energy potential of the biogas that is produced from the AD process. Because of its historical use in MA, the state also has eight facilities with unused existing digesters in various conditions. Each of these cases provides examples of effective implementation, lessons learned and opportunities for growth, but the small proportion of all WWTPs that have employed these technologies necessitates a more detailed discussion of the regional and historical challenges.

MWRA Deer Island WWTP

Facility Facts	
Design Flow	1313 MGD
Average Flow	365 MGD

[20] Personal Communication with Jim Jutras of the Essex Junction WWTP by Shutsu Wong on June 29, 2010.

CHP System Type	3.28 MW steam turbine generator
Percent of Total Energy Needs Generated On-Site	17.7%

Deer Island's iconic egg-shaped digester system was built between 1995 and 1998 through a combination of bonds and federal and state assistance, driven by efforts to improve the water quality of the Boston Harbor. Each of the twelve digesters has a capacity of three million gallons. On average, Deer Island processes wastewater at less than a third of its total capacity (365 MGD average flow, 1313 MGD design flow), with volumes peaking during large storm events.

This facility demonstrates that significant savings are available from reduced disposal costs alone when AD is applied. At Deer Island, given 65 percent reductions in volatile solids, 55 percent reductions of total solids and disposal costs of $350 per ton, yearly savings may be as high as $10 million.

In addition to the twelve digesters, Deer Island also has a 3.28 megawatt (MW) steam turbine generator. Based on the 2010 fiscal year (FY2010) operations, the facility consumed 166,799 MW and generated 40,127 MW.[21] Thus, at present, this facility is generating a little over 24 percent of its energy needs on-site through this CHP system. In FY2010, the average cost per kWh was reported as $0.10427[22], which would yield a cost savings of approximately $4.2 million for the year from onsite energy generation. If this facility were to utilize a greater proportion of its digester capacity through the addition of other waste streams, Deer Island could boost its onsite energy generation potential and achieve even greater cost savings.

Greater Lawrence Sanitary District

Facility Facts	
Design Flow	52 MGD
Average Flow	31 MGD
CHP System Type	N/A
Percent of Total Energy Needs Generated On-Site	N/A

The facility for the Greater Lawrence Sanitary District (GLSD) currently employs anaerobic digestion and utilizes the gas to power their pelletization process. This system was built in 2002 with three digesters

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[21] "Deer Island Wastewater Treatment Plant FY 2010 Key Operations Data." PDF file provided by facility on March 4, 2010.

[22] "Deer Island Wastewater Treatment Plant FY 2010 Key Operations Data." PDF file provided by facility on March 4, 2010.

for a 4.2 million gallons total capacity. The design flow of the WWTP is 52 MGD, and the average flow is 31 MGD. More specifically, the digester gas is used to maintain digester temperatures and for onsite sludge drying and pelletizing; the excess is currently flared, but a boiler system for capturing the excess is currently being explored for heating the administrative buildings in the winter.

GLSD has developed an effective public-private partnership with the New England Fertilizer Company (NEFCO); while GLSD maintains the wastewater treatment and digester processes, NEFCO operates and maintains the pelletization process and manages the sale of the pellet product that is used for land application. At the outset of the partnership, NEFCO also designed and constructed the pelletization facilities that they now own and operate. [23] This type of partnership contracting lifts a portion of the initial cost burden from the municipality, making the project more financially and technically feasible.

Clinton and Rockland WWTPs

The Clinton and Rockland facilities in MA are two smaller facilities that employ anaerobic digestion without CHP systems. The biogas that is produced is used to maintain digester temperatures, but due to the size of the systems, there is insufficient gas to make CHP cost effective; payback estimates are long and therefore not attractive.[24] These types of facilities would be good candidates for additional feedstocks that would increase their methane productivity, making CHP systems more economically viable.

Facility Facts – Clinton WWTP	
Design Flow	3.01 MGD
Average Flow	2.4 MGD
CHP System Type	N/A
Percent of Total Energy Needs Generated On-Site	N/A

The Clinton WWTP is an MWRA facility, and it currently uses the biogas in dual boilers to maintain digester temperatures. Clinton processes 2.4MGD on average and has a design flow of 3.01 MGD. Based on the estimates of biogas volumes that could be produced from its average flow, a 2008 feasibility study concluded that payback for a new CHP system would have a 25-27 year payback and was therefore not recommended for the facility.[25] While there may be excess biogas at the facility

[23] 2010 North East Residuals and Biosolids Conference: Greater Lawrence Sanitary District Plant Tour. November 9, 2010.

[24] Personal communication with John Riccio at Clinton WWTP by Shutsu Wong. June 15, 2010.

[25] "Massachusetts Water Resources Authority: Clinton Wastewater Treatment Plant Microturbine Feasibility Assessment." Green International Affiliates, Inc. Consulting Engineers and CDM. October 2008.

during the summer months, the flows are inadequate to produce sufficient biogas to maintain the boilers alone during the winter months.[26] Thus, savings would only be attained during the warmer months when there is excess biogas for electricity generation, drawing out the payback period.

Rockland Facility Facts	
Design Flow	2.5 MGD
Average Flow	2.5 MGD
CHP System Type	N/A
Percent of Total Energy Needs Generated On-Site	N/A

The Rockland WWTP also uses boilers to heat its digesters. Its design flow is 2.5 MGD and has a average flow of 2.5 MGD. In this case, low gas production results from the low biosolids concentration of wastewater arriving at the facility; due to problems with inflow and infiltration within the wastewater collection system, the wastewater is quite dilute.[27] Again, the small size of the facility and insufficient quantities of biogas limit the economic viability of installing a CHP system.

Pittsfield, MA

Facility Facts	
Design Flow	17 MGD
Average Flow	12 MGD
CHP System Type	3 x 65kW microturbines
Percent of Total Energy Needs Generated On-Site	29%

Next is a case study in Pittsfield, MA, made possible through a Massachusetts Technology Collaborative (now the Clean Energy Center) grant for its initial feasibility study (approximately $40,000) and $16 million in stimulus grants through the Clean Water State Revolving Fund (SRF), where $1.67 million went

[26] Personal communication with John Riccio at Clinton WWTP by Shutsu Wong. June 15, 2010.

[27] Personal communication with Tony Olivadesa at Rockland WWTP by Shutsu Wong. June 21, 2010.

towards the AD and CHP system.[28] This funding enabled an upgrade of its existing digesters and the installation of a new CHP system, three 65kW microturbines.

With the installation of the new CHP system, the facility is anticipating that 29 percent of its total energy needs can be generated on site.[29] Through its feasibility study and funding, Pittsfield worked with SEA consultants to also explore the potential of incorporating fats oils and grease (FOG) into its system to maximize biogas and energy production.

Most notable about this project, the projections for this project demonstrate the potential for *positive cash flow* for the facility even in the first year. Pittsfield invested $1.67 million in SRF funding for the project. With an estimated energy savings of $206,000 each year,[30] simple payback would occur in 8 years. Looking on a cash flow basis, assuming a ten year loan and incorporating their anticipated renewable energy credits, Pittsfield has over $66,000 in cash flow within the first year. (See calculations below.) These cash flows do not even incorporate other costs savings such as reduced sludge disposal costs. That said, AD and CHP has the potential to help municipalities with their bottom lines and can make even more sense if other organic waste streams are considered to help boost energy generation!

Figure 1: Pittsfield Financial Anaylsis on Cash Flow Basis

Anaerobic Digestion Upgrade and New Microturbines (195kW)

- Investment: $1.67M
- Estimated annual energy savings: $206,000 (29%)
- Simple Payback: 8.0 years

From a cash flow perspective:

- Apply annual energy savings to pay for loan debt
  (assume a 10 year loan with a 2% and 3% annual rise in electricity costs,
  annual loan payment: $184,395)
- Potential Renewable Energy Credit (REC) Revenue: $45,000[31]

[28] "Massachusetts Energy Management Pilot: Pittsfield Wastewater Treatment Facility." Massachusetts Department of Environmental Protection. Web. http://www.mass.gov/dep/water/wastewater/empilot.htm#pitt>. Accessed August 12, 2010.

[29] "Massachusetts Energy Management Pilot: Pittsfield Wastewater Treatment Facility." Massachusetts Department of Environmental Protection. Web. http://www.mass.gov/dep/water/wastewater/empilot.htm#pitt>. Accessed August 12, 2010.

[30] "Massachusetts Energy Management Pilot: Pittsfield Wastewater Treatment Facility." Massachusetts Department of Environmental Protection. Web. http://www.mass.gov/dep/water/wastewater/empilot.htm#pitt>. Accessed August 12, 2010.

[31] "City of Pittsfield: Feasibility Study – Wastewater Treatment Plant." April 1, 2008. SEA Consultants, Inc.

Annual Energy Savings	+	REC Revenue	-	Annual Loan Payment	=	$66,605 Positive Cash Flow!
$206,000		$45,000		$184,395		

With low interest and no interest loans available through the state revolving funds, the economics of adopting AD and CHP work in the favor of municipalities. With water utilities and WWTPs accounting for 30-60 percent of a municipality's energy bill, the potential for positive cash flow from a WWTP makes AD and CHP even more financially attractive.[32]

Fairhaven, MA

Facility Facts	
Design Flow	5 MGD
Average Flow	2.7 MGD
CHP System Type	1 x 110 kW, 1 x 64 kW internal combustion engines
Percent of Total Energy Needs Generated On-Site	26% (initially), 73% (after phase-in of other organic waste)
Total AD + CHP Cost	$7.2M

In 2011, the city of Fairhaven will have the state's newest AD and CHP system at a municipal WWTP. Unlike Pittsfield, Fairhaven did not have existing digesters to upgrade; this project involved the installation of completely new digesters. As a consequence, the overall project was more costly. Through examining the financials of this project, several important factors emerge regarding the adoption process of AD and CHP at municipal facilities.

First, Fairhaven's experience demonstrated the importance of feasibility studies in achieving community acceptance of the new digesters and CHP systems.[33] The study convinced community members that the incorporation of FOGs into the feedstock was a win-win situation, where the addition enhanced the methane production potential of the digester system while minimizing backups in the wastewater collection system from clogged grease traps.[34] Project acceptance by the community as a result of the feasibility study confirmed the importance of feasibility studies in the public process.

Second, Fairhaven's experience demonstrated the impact financial incentives can have. The following table is extracted from the feasibility study conducted by Brown and Caldwell for Fairhaven,

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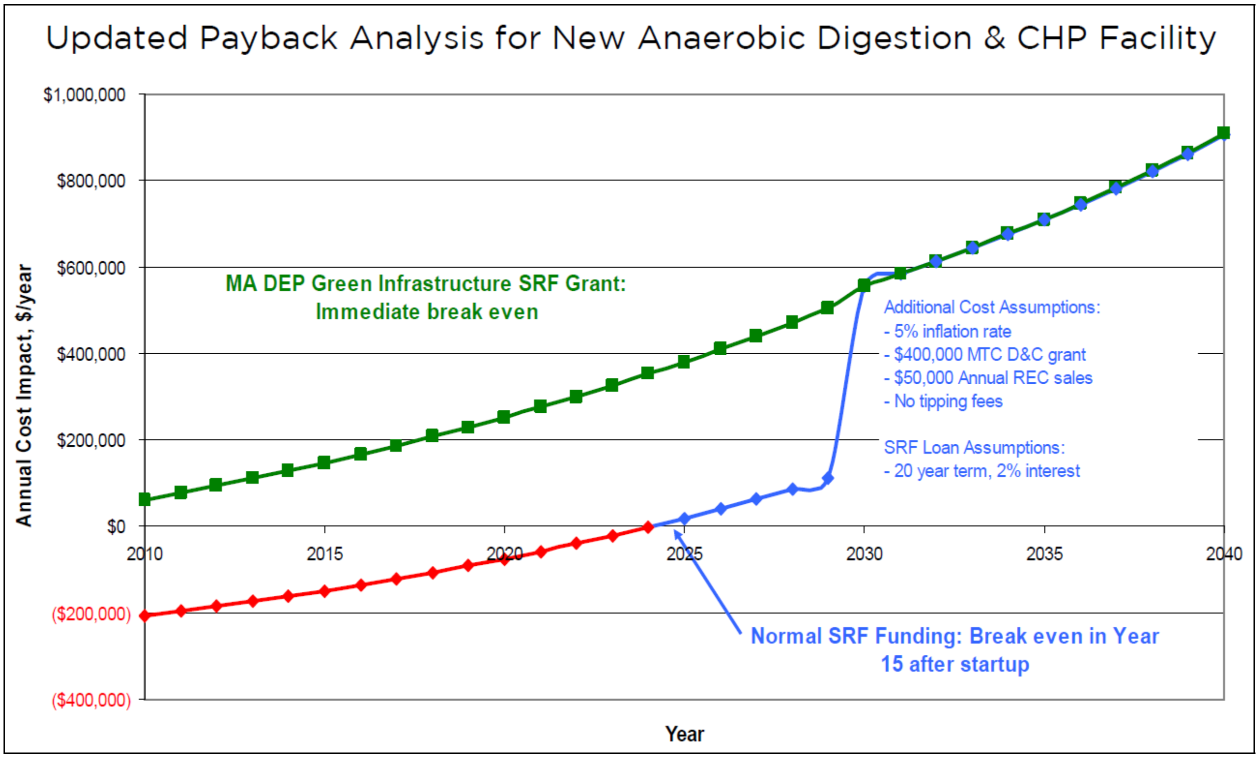
[32] "Ensuring a Sustainable Future: An Energy Management Guidebook for Wastewater and Water Utilities." Office of Watewater Management of the U. S. Environmental Protection Agency with the Global Environment and Technology Foundation. January 2008.

[33] Personal Communication with Bill Fitzgerald of the Fairhaven WWTP by Shutsu Wong. October 4, 2010.

[34] Personal Communication with Bill Fitzgerald of the Fairhaven WWTP by Shutsu Wong. October 4, 2010.

demonstrating the impact of the Green Infrastructure SRF Grant on the payback for the new AD and CHP system:

Figure 2: Payback Analysis from Fairhaven's Feasibility Study by Brown & Caldwell



Closer examination of the projected payback schedule shows that, with normal SRF funding, the project would have broken even in 15 years, which is considered a long time for a municipal project. In contrast, given the $7.9M Green Infrastructure Grant, the facility will be able to have positive cash flows from the outset of the project. While this is a special case, Fairhaven's financial projections show us the impact of financial incentives to transform payback schedules and to make these projects more appealing for municipalities. Financial incentives do not need to cover the entire cost of a project; attractiveness of AD and CHP can be improved by simply shortening payback to a more reasonable time period. Thus, the financial incentive had a dramatic impact on the payback period, which affected the acceptability of the project for the community and municipality.

Offline Digesters

And finally, this series of MA facilities concludes with the list of facilities that have been identified as having old digesters that are not in use. They vary in their level of connectedness and usability to the facilities, ranging from completely disconnected and overgrown to being used for sludge storage. The following table summarizes the status of these WWTPs:

Figure 3: MA WWTPs with unused, existing digesters[35]

Facility Name	Average Flow (MGD)	Design Flow (MGD)
Springfield Regional Wastewater Treatment System	43	67
Brockton Wastewater Treatment Plant	17	18
Leominster Wastewater Treatment Plant	5 - 6	9.3
Attleboro Wastewater Treatment Plant	4	8.6
Northampton Wastewater Treatment Facility	3.5 - 4.0	8.6
Newburyport Wastewater Pollution Control Facility	2.6	3.4
Ipswich Wastewater Treatment Plant	1.1	1.8
Ware Wastewater Treatment Plant	0.817	2

Although these facilities may require significant adaptations to reinstate AD and to add CHP systems, these facilities can be opportunities for intervention. With existing space dedicated to these digesters and potential connections to the wastewater treatment process, these facilities may be favorable starting points for any efforts to encourage AD and CHP adoption in the state.

Given that of the 133 facilities in MA, only six have or will have AD, and of those six, only four will have CHP systems, the state of WWTPs begs the question of why so few facilities have these technologies, beyond the historical challenges and experiences.

Known Challenges and Potential Mechanisms for Intervention

While a strong case exists for developing a waste to energy strategy for our state based on AD and CHP, there are some financial, technical, operational, political and regulatory challenges and opportunities that must be addressed to make any program effective. This section gathers the concerns and obstacles that emerged through discussions with state WWTPs while coupling them with potential solutions. Practically, this section is an overview of necessary considerations when developing a waste to energy program at municipal WWTPs.

Financial Challenges

The most commonly cited challenges are financial, which include a wide range of costs from preliminary assessments to design and construction. There are also financing decisions that must be made, and in

[35] Data gathered through personal communications by Shutsu Wong with MA Regional Contacts: Kevin Brander (Northeast), Paul Nietupski (West), Robert Kimball (Central) and David Burns (Southeast). August 2010 through November 2010.

the case that facilities generate so much energy they cannot use it all onsite, they will need help to make interconnection to the grid possible.

The initial capital investment for digesters, pumping mechanisms, piping, and energy generators are high, making the costs prohibitive. Most plants and cities, particularly in the current economic climate, understandably have limited funds to invest in large capital projects. In addition, when funds are available, new wastewater treatment technologies are not at the top of the priority list. Some cities noted that existing regulations, particularly those for combined sewer overflows, take priority as they are mandated while taking advantage of renewable energy is not. Despite these financial limitations, facilities and municipalities have funding opportunities that are outside of the typical financing structure of these WWTPs. These potential sources come from varying levels of government and groups that can enable different stages of the planning process for a WWTP. These stages include initial facility audits, feasibility analyses and design for construction. Some of these, funds, particularly those related to the current economic climate such as the American Recovery and Reinvestment Act (ARRA)[36] are specific to the time period and provide significant financial support if plants choose to capitalize on the immediate opportunities.

In addition to capital costs, concerns were raised about eventual payback. Arguably, the future is uncertain, and thus, the thought of such a large capital investment with long-term payback may be a difficult decision. Nonetheless, *energy costs are anticipated to grow with time*, and although that is not 100 percent certain, *there is reasonable certainty that that prediction will hold true*. The case of Sheboygan, WI confirms how energy costs can indeed rise at dramatic rates, rising between 70 and 100 percent between 2002 and 2008.[37]

Not only are the costs of energy consumption onsite reduced, the costs of sludge disposal are also reduced. Those costs include transport offsite and payments to someone else to either landfill or process that sludge for other uses such as fertilizer. Cost reductions, particularly in this area of sludge disposal, *are* certain. Disposing less sludge cannot cost more than disposing more sludge. Moreover, if that sludge has a productive use such as soil amending following the AD stabilization process, the sludge could become a revenue generator as opposed to an expense. In the case of the Greater Lawrence Sanitary District, the sludge is pelletized and sold as a soil amendment with the help of NEFCO, and thus, tipping fees for disposal are no longer needed.

[36] "Patrick-Murray Administration receives $185M in Federal Recovery Act Funds for Water Treatment Projects." Website of the Governor of Massachusetts. June 15, 2009. Web. June 17, 2010. http://www.mass.gov/?pageID=gov3pressrelease&L=1&L0=Home&sid=Agov3&b=pressrelease&f=090615_water_treatment&csid=Agov3.

[37] See Sheboygan, WI WTTP case study.

Funding Opportunities

In addition, despite the financial challenges, there are a whole host of funding opportunities ranging from leases to grants to revenue streams that are directly generated by the addition of AD and CHP for biosolids management. These funding opportunities include means such as: state and federal grants and loans, private and non-profit grants (e. g. National Grid), study grants (e. g. research foundations like the Water Environment Research Foundation), bonds, renewable energy credits, and a facility's own expanded revenue streams (e. g. tipping fees for receiving industrial food processing wastes). Although less traditional, public-private partnerships are also opportunities to consider.

In situations where the installation of a CHP system may not be economically feasible, direct connections to the natural gas pipeline are also an option. Ameresco, a Framingham based energy solutions provider, is one company that helps cities to manage a direct connection to the natural gas pipeline. Its first contract to make this connection was for the city of San Antonio in Texas. Within the contract, Ameresco will manage every step of the implementation process, from design and engineering to owning and operating the entire system. Ameresco will even condition the gas and maintain the necessary pipelines.[38] In this case, partnerships can be established with natural gas suppliers, where the provider may supply a portion or even all of the capital costs. While the plant may not receive as much financial gain from this setup, it presents an alternative to plant- (or city-) funded capital investments.

While high capital costs can be prohibitive for a municipal WWTP, two other public-private management systems are available that can minimize costs borne by the municipality while still providing environmental and financial benefits. First, a contractor can be selected to manage the operations of the WWTP as is done in several of MA WWTPs already including Springfield WWTP with United Water and Lynn WWTP with Veolia Water. As a profit-maximizing entity, they are able to do the cost-benefit analyses and make the decisions that will maximize their profit. If contracts last longer than payback for a system (average contracts are for around 20 years), this relationship could result in capital investments by the contractor in AD and CHP. Second, an outside company can be contracted to develop and operate new AD and CHP systems. For example Alcor Energy Solutions will design, install, operate and maintain a CHP system for a WWTP, thus requiring no capital investments and no additional training of personnel for the WWTP.[39] In the cases of Sheboygan with Alliant Energy and Greater Lawrence with NEFCO, a sharing of the costs and capital enabled technological adoption at these facilities.[40] These forms of performance contracting are available to facilities that choose to adopt AD and CHP and that are open to public-private partnerships.

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[38] "Ameresco Executes Historic Renewable Energy Contract." Ameresco. September 11, 2008. Web. February 2, 2010. http://ameresco.com/release.asp?ID=180.

[39] Personal communication with Tom Broderick of Intermountain CHP Application Center by Shutsu Wong on June 17, 2010.

[40] See Sheboygan, WI WTTP case study.

Technical Challenges and Advances

As the history of AD demonstrates, there are clearly technical challenges that must be overcome for these systems to work at WWTPs. Although these challenges may seem daunting, technological advances have addressed many of these concerns, including the historical challenges from the 70s and 80s. As digester technologies have been used for the last thirty years, this section establishes the "state-of-the-art" for AD and CHP to demonstrate how technological advances have helped address some of those issues. While some concerns were truly limiting, others can now be addressed; as with any technology, with time, constraints have been mitigated, and the possibilities have grown. Where challenges in managing secondary sludge stemmed from the differences from primary sludge, processes have now been better adapted to manage secondary sludge and its distinct characteristics. This section identifies those technical obstacles and the solutions that have emerged. This discussion will enable interested parties to avoid some of these setbacks while helping to help others understand and take advantage of the advances in this technology and the barriers that have already been overcome.

One concern is that of *odor control*. For example, at the New Bedford Wastewater Treatment Plant, odor control is an especially dominant concern regarding the treatment process as a whole. With nearly 50 percent of the industries feeding wastewater into the wastewater stream as fish processing industries, the resulting water composition leads to especially pungent odors.[41] In addition to odorous water, the plant is situated especially close to the surrounding residential community and well-frequented recreational open space. This proximity and level of odor has forced the plant to conduct all of its treatment processes either within buildings or below ground.[42] For a plant like New Bedford, where the composition of wastewater and the proximity of the community to the plant pose tight constraints, managing odor can be especially important.

By the nature of the AD process, a digester system *can* effectively manage odors. An anaerobic process, AD requires a sealed environment for the digestion to occur. As the gases are produced, the sealed environment is essential to capturing the biogas for use. In light of these two requirements for AD, AD effectively prevents the escape of odorous gases during digestion. According to Alan Wells of SEA Consultants, an engineering and architecture firm based in Cambridge, MA, the dewatering process of sludge, which occurs at just about *every* wastewater treatment plant, is the true source of odors. For a plant like New Bedford, where even dewatering onsite is a challenge because of odors, AD may not be possible, but for other plants where dewatering *does* occur onsite, AD does not complicate odor management. Moreover, the use of CHP with an AD system enables a facility to capture and use methane, limiting any methane odors that may otherwise occur from the breakdown of organic materials at the WWTP.

[41] Personal communication with Vinnie Furtado of the New Bedford WWTP by Shutsu Wong. April 25, 2010.

[42] Personal communication with Vinnie Furtado of the New Bedford WWTP by Shutsu Wong. April 25, 2010.

Another challenge of using biogas for CHP is the conditioning of the gas to remove *biogas contaminants* prior to use. Contaminants can include water, siloxanes, hydrogen sulfides and chlorine. These contaminants can affect the efficiency and function of CHP systems if they are not removed prior to use as fuel. Some CHP systems are more sensitive to the level of cleanliness of the biogas; microturbines and engines can be corroded by siloxanes if biogas is not cleaned while steam boilers require little biogas cleaning as the steam serves as a clean intermediary. Conditioning can be a costly operation and is necessary to some extent for most CHP systems. These design decisions about which CHP system to employ and the level of conditioning necessary are made during the design and engineering process; consequently, in the hands of an expert, this challenge is not difficult to overcome.

Production fluctuations are also a concern for treatment plants. As noted above, some plants utilize backup natural gas sources to ensure that fluctuations do not detract from the benefit that can be attained from employing a CHP system for onsite power generation. For a small plant like the Clinton WWTP, seasonal fluctuations were enough to make the payback of a CHP system unreasonable. All digester gas is consumed for heating buildings and digesters during the winter; were a CHP system to use all of the biogas produced by the digesters, the cost of supplemental propane or natural gas to maintain digester temperatures for those months dramatically lengthen payback.[43] Thus, despite the coupling of CHP and AD installations in this study certain situations may benefit from AD alone, and CHP may not be necessary for maximizing the benefits of digester gas, particularly for smaller WWTPs.

Where adequate production of biogas is a challenge, there are also other solutions such as the introduction of high strength food wastes. A good example is the Village of Essex Junction, VT. There, high strength wastes are fed to the digesters on a schedule and as needed to maintain digester gas production; controlled addition of these wastes enable management of consistent gas production.[44] Another good example is the Gloversville-Johnstown WWTP in NY; partnering with the dairy processors in its industrial park enabled this facility to generate enough energy onsite to be self-sufficient.[45] This demonstrates the capacity of high strength waste inputs from industry to maintain and even enhance biogas production, especially when incorporated as an additional input stream at municipal plants. Thus, partnering with industry is one means to enable facilities to overcome challenges with production fluctuations.

As alluded to earlier, *space constraints* also pose challenges for the adoption of AD and CHP. Digesters can have large footprints; the size of these systems varies by design, but the total volume of these

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[43] "Massachusetts Water Resources Authority: Clinton Wastewater Treatment Plant Microturbine Feasibility Assessment." Green International Affiliates, Inc. Consulting Engineers and CDM. October 2008. and Personal communication with John Riccio at Clinton WWTP by Shutsu Wong. June 15, 2010.

[44] Personal communication with James Jutras, Water Quality Superintendent at the Village of Essex Junction WWTP in Vermont, by Shutsu Wong. June 22, 2010.

[45] See Gloversville-Johnstown case study.

digesters is determined by the volumes of wastewater treated on a daily basis. Digesters simply need adequate volume to contain sludge while it is being digested. Digesters for AD have not changed significantly in size over time and still pose an obstacle for plants that preclude using AD, but some design modifications such as the patented egg-shape can enable lower sludge retention times, reducing the amount of holding volume necessary at any time point. Furthermore, the addition of organic wastes can also decrease the retention time necessary for digestion, a property demonstrated through the East Bay Municipal Utility District's bench scale studies.[46] Both of these advances can enable some reductions in footprint size.

While the producers of CHP technologies are abundant, the CHP *technology distributors that have expertise with digester gas are limited*. Digester gas has many contaminants that may corrode components or limit CHP system efficiencies. Consequently, CHP systems for application at WWTPs must be coupled with an effective fuel conditioning system to adequately clean the digester gas (a non-traditional fuel as compared to natural gas) before use. In the experience of Joan Fontaine at SEA Consultants, there were only three companies (Ingersoll Rand, Elliot and Capstone) that provided microturbines for digester gas while the company was developing its feasibility study for the Pittsfield, MA WWTP. Of those companies, Ingersoll Rand discontinued their 70kW turbine during the course of the study and Elliot did not provide fuel conditioning; consequently, Capstone was selected by default.[47] While providers are currently limited, the market will respond to demand, and as the state encourages the uptake of AD and CHP technologies, the number of potential venders can be expected to grow.

Other operational challenges like struvite remediation (buildup within pipes leading to and from digesters that can constrict flow rates) and foaming in digesters can complicate the implementation of AD and CHP.[48] Furthermore, the introduction of new technologies to a facility would also require new training and processes to adequately operate and maintain the systems. But, at the same time, these "new technologies" are not entirely new; piping systems and valves and other components are similar if not identical. Thus, these challenges can be overcome through contracting relationships where the company that installs the system can be called upon for specialized maintenance until the existing personnel are comfortable taking on those efforts.[49] Through communications with facilities using AD and CHP, it also appears that these facilities also learn from the experiences of one another as challenges arise. Other challenges include the risk averse nature of WWTP operators in light of the

[46] "Turning Food Waste into Energy at the East Bay Municipal Utility District: Investigating the Anaerobic Digestion Process to Recycle Post-Consumer Food Waste." East Bay Municipal Utility District.

[47] Personal communication with Joan Fontaine of SEA Consultants by Shutsu Wong on June 15, 2010.

[48] Personal communication with Richard Hogan of the Greater Lawrence Sanitary Sewer District by Shutsu Wong. April 16, 2010.

[49] Personal communication with Tom Broderick from Intermountain CHP Application Center by Shutsu Wong on June 17, 2010.

complications of using old AD systems in the 1980s.[50] In the present day, many of those complications have been overcome through application of AD after secondary treatment as opposed to primary treatment; education and experience with the new systems will enable operators to overcome these fears.[51]

Yet another challenge is the need for new processes to continually adapt to ever-changing and increasingly stringent environmental regulations; the output of AD needs to be able to meet those standards before it will be embraced. While supernatant quality is still a challenge, denitrification has improved its management.[52] Facilities will also have to learn and adapt to process changes to manage operations such as sludge mixing and food slurrying (if additional organic waste streams are considered). Another challenge that was cited included the treatment of waste-activated sludge, the sludge that has already been treated by AD and has high concentrations of the microorganisms responsible for digestion; research in this area has developed improved mechanisms for cell lysis like ultrasonic cell bursting to facilitate treatment and disposal.[53] Lastly, concerns have been raised regarding the potential toxicity of the AD byproduct if used for land application; ongoing research in this area will be needed to clarify these impacts.

Operational Challenges and Support

Operational challenges stem from new processes, where operation and maintenance procedures change. Operators are often resistant to this change due to past history with AD and reluctance to adapt to a new system with potential process upsets when the existing systems work well. Furthermore, other organic waste streams are to be integrated into the wastewater treatment process for greater biogas potential, conveyance of those waste streams to these WWTPs will also be a challenge.

Despite the operational challenges, there are options to mitigate these difficulties to make AD and CHP adoptable at our WWTPs. Through learning and training and perhaps even something like a central technical support system can enable effective operation of AD and CHP at municipal facilities and provide confidence to operators considering the use of these technologies. In the case of Strass in Zillertal, Austria, through additional training in process optimization, the facility was able to achieve great operational efficiencies.[54] While conveyance may pose a challenge, many of the frontrunners in

[50] David Ferris of MA DEP at a July 13, 2010 meeting discussion.

[51] David Ferris of MA DEP at a July 13, 2010 meeting discussion.

[52] Appels, Lise, Jan Baeyens, Jan Degrève, Raf Dewil. "Principles and potential of the anaerobic digestion of waste-activated sludge." Progress in Energy and Combustion Science. (2008). Volume 34. p. 755-781.

[53] "City of Pittsfield: Feasibility Study – Wastewater Treatment Plant." April 1, 2008. SEA Consultants, Inc.

[54] "Case Study: Sustainable Treatment: Best Practices from the Strass in Zillertal Wastewater Treatment Plant." Water Environment Research Foundation. March 2010.

incorporating organic waste have developed or are in the process of developing solutions. Gloversville-Johnstown WWTP has strategically developed an industrial park such that dairy processing wastes can have direct pipelines to the WWTP (see the Gloversville-Johnstown case study).[55] East Bay Municipal Utility District in Oakland, CA is currently developing its waste collection system to increase its collection from 20 to 40 tons a week to 200 tons a week[56] and will soon have experience to provide.

Ultimately, the operational challenges associated with adopting AD and CHP as well as any of its associated processes and technologies can be overcome through learning. As the many case studies prove that these operations are manageable, these operational challenges are no limitations if a facility operator or manager is willing to seek out the experiences and knowledge of others.

Political Challenges

Overcoming political challenges are a significant component of turning waste to energy ideals into reality. Those challenges include obtaining the support of the decision-makers of a community such that these strategies can be implemented at all, facility siting and site use changes that need to be approved by the communities as well as other community impacts and concerns. Especially important in MA is the need for public acceptance. As discussed earlier, focusing the introduction of AD and new waste streams to existing WWTPs (as opposed to siting completely new waste treatment sites for diverting organic wastes) will be one way to address this concern.

Another challenge that municipalities may face in adopting AD and CHP is their management structure for their WWTP. As cities are not profit-maximizing entities, they face greater obstacles to simply making the most cost-effective decisions; contractors, on the other hand, operate based on their bottom line and are free to make decisions in their own financial interest.[57] For municipalities, optimizing the capital investment and technology adoption process is more complicated; issues like low-bid regulations limit the use of best technologies.[58] Each city has a different system, some WWTPs answering to boards while others simply answer to the department of public works. The long-range view of each player affects the types of energy decisions that can and will be made for each facility.

[55] "Is it a Digester or a Power Plant? Anaerobic Digestion and CHP at the Gloversville-Johnstown Joint Wastewater Treatment Plant." Presented by Robert Ostapczuk, Malcom Pirnie. Northeast Residuals & Biosolids Conference. November 9, 2010.

[56] Personal communication with Donald Gray at the East Bay Municipal Utility District by Shutsu Wong. November 1, 2010.

[57] Personal communication with Doug Bogardi at Springfield WWTP by Shutsu Wong on April 26, 2010.

[58] Personal communication with Doug Bogardi of Springfield WWTP by Shutsu Wong on April 26, 2010.

Regulatory Challenges and Opportunities

Perhaps just as limiting are regulatory challenges that constrain what can ultimately be done at a WWTP. The myriad of permits from different levels of government can be conflicting and complicated to navigate. Furthermore, increasingly stringent discharge permits preclude system changes with fears of implications on effluent quality and nutrient loading.

While there are no easy solutions, state regulations offer the opportunity to explore ways to encourage the desired behaviors, and in this case, the capture of the energy potential contained within biosolids. Moreover, the state has the opportunity to help interested parties navigate the sometimes complex regulatory pathways, facilitating the transformation of these waste-to-energy ideals into reality.

Non-MA Case Studies

Despite the many challenges, many facilities and municipalities are choosing to adopt AD and CHP. Their success confirms the importance of these technologies from both an economic and environmental standpoint. This next section presents a set of case studies, each with a unique set of incentives and circumstances that made AD and CHP both possible and effective for solid waste management and energy recovery. These conditions provide insight for areas to target while designing an effective waste to energy program for Massachusetts.

East Bay Municipal Utility District, California

Facility Facts	
Design Flow	168 MGD
Average Flow	75 MGD
CHP System Type	3 x 2.15 MW engine
Percent of Total Energy Needs Generated On-Site	90%

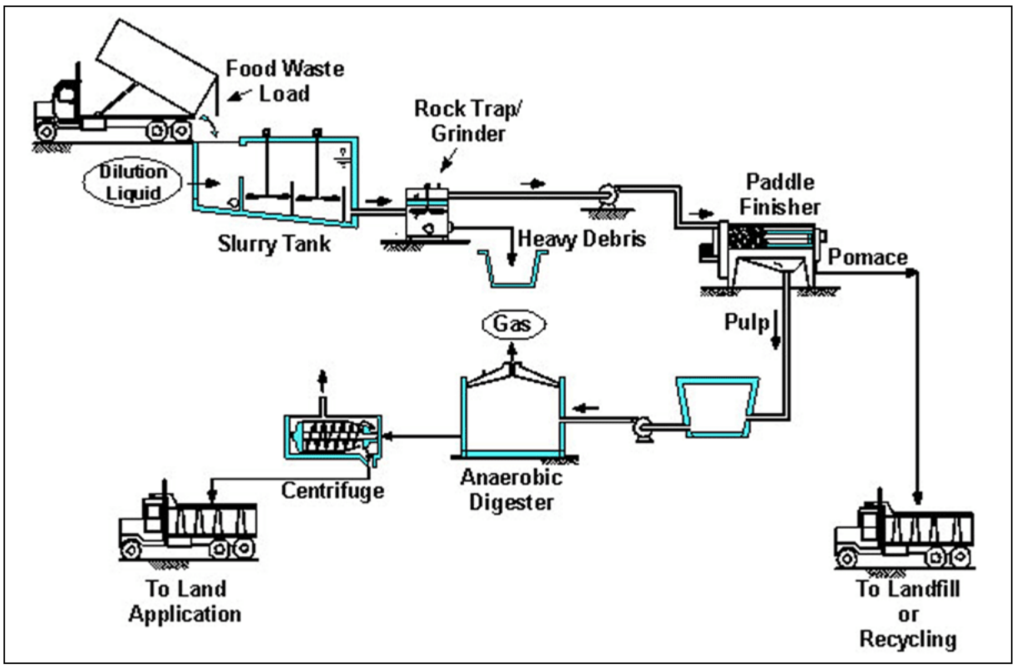
The East Bay Municipal Utility District (EBMUD) manages the water resources of East San Francisco Bay in California, providing water and treating wastewater before its discharge into the San Francisco Bay. While inauspicious in its mission, EBMUD has far surpassed its charge for wastewater treatment; EBMUD is in fact a resource recovery facility through its wastewater treatment processes. Designed to treat 168 million gallons per day of wastewater, EBMUD currently treats 75 million gallons per day on average.[59] EBMUD was designed to treat wastewater for industries that have since moved from the

[59] "Wastewater Online Tour." East Bay Municipal Utility District. <http://www.ebmud.com/wastewater/online_tour>. Accessed August 3, 2010.

region, leaving significant excess capacity at the treatment facility.[60] With over 50 percent of the total capacity unused, EBMUD sought means of using more of that capacity. EBMUD's program, the first of its kind in the nation, incorporates two primary waste streams beyond water – food wastes and fats, oils and grease (FOG).

The excess capacity, coupled with a local ban of organics in landfills, generated a new market for EBMUD to capture through its trucked waste program. At present EBMUD is receiving 20 to 40 tons of food waste per day, but the facility has the capacity for up to 200 tons per day and is currently exploring the collection methods to make this possible.[61] Through this program, EBMUD has not only generated new revenues from tipping fees, but it has also patented its food waste treatment process (see below for process diagram) and demonstrated the clear benefits of the addition of food waste to AD. In fact, EBMUD is nearing 100% onsite energy generation.

Figure 4: EBMUD's Food Scraps Processing System[62]



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[60] "Turning Food Waste into Energy at the East Bay Municipal Utility District (EBMUD): Wastewater Treatment Facilities Taking Food Waste." U.S. Environmental Protection Agency, Region 9: Waste Programs. <http://www.epa.gov/region9/waste/features/foodtoenergy/wastewater.html>. Accessed August 3, 2010.

[61] Personal communication with Donald Gray at the East Bay Municipal Utility District by Shutsu Wong. November 1, 2010.

[62] "EBMUD's Food Treatment Process: Preparing the Food for Digestion." U.S. EPA Region 9: Waste Programs. <http://www.epa.gov/region9/waste/features/foodtoenergy/ebmud-process.html>. Accessed January 26, 2011.

In addition to effectively using AD and CHP at their facility, EBMUD has also worked with the EPA to demonstrate the impacts of adding food waste to the digesters. Through a grant from the EPA Region 9 Resource Conservation Fund, EBMUD conducted a bench-scale study that demonstrated the higher yields of methane and greater volatile solids destruction with food waste as compared to municipal solids.[63]

The following provides a detailed comparison of food waste and municipal wastewater solids based on this study:

Figure 5: Food Waste vs. Wastewater Solids Comparison[64]

Parameter	Food Waste Pulp	Wastewater Solids
Volatile Solids in Feed (%)	85-90	70-80
Volatile Solids Loading (lbs/ft^3-day)	0.60+	0.20 max
COD Loading (lbs/ft^3-day)	1.25+	0.06-0.20
Total Solid Fed (%)	10+	4
Volatile Solids Reduction (%)	80	56
Hydraulic Detention Time (days)	10	15
Methane Gas Produced ($meter^3$/ton)	367	120
Gas Produced (liters/liter of feed)	58	17
Biosolids Produced (lbs/lbs fed)	0.28	0.55

In addition to greater methane production potential by three times and increased volatile solids destruction by one and a half times, food waste also had two-thirds the detention time and nearly halved the amount of biosolids produced by the process. To summarize the primary advantages of food wastes in anaerobic digesters according to this study, food waste results in greater energy production potential and reduced solids disposal volumes in a shorter amount of time, all leading to greater operational costs savings for a WWTP.

EBMUD's study provided a controlled analysis of the benefits of adding additional organic waste streams to digesters. In addition, it presented a strong case for considering waste streams beyond the traditional wastewater streams found at WTTPs by demonstrating that food wastes have the potential to enhance the benefits already associated with AD and CHP.

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[63] "Turning Food Waste into Energy at the East Bay Municipal Utility District: Investigating the Anaerobic Digestion Process to Recycle Post-Consumer Food Waste." East Bay Municipal Utility District.

[64] Adapted from: "Turning Food Waste into Energy at the East Bay Municipal Utility District: Investigating the Anaerobic Digestion Process to Recycle Post-Consumer Food Waste." East Bay Municipal Utility District.

Strass in Zillertal, Austria

Facility Facts	
Design Flow	10 MGD
Average Flow	5 MGD
CHP System Type	340 kW co-generation engine
Percent of Total Energy Needs Generated On-Site	Over 100%

Second is an international example from Strass in Austria, where, through optimized plant operations in both AD and CHP led to electricity generation that was sufficient to meet all of the energy needs onsite. Changes included improved methane production of the AD system and increased overall energy efficiency of the facility at every step of the waste treatment process. [65]

These optimizations were made possible through a highly educated work force and advanced process analysis tools. Because of these operators and tools, the system was sufficiently flexible and adequately equipped for *constant* optimization to ensure that efficiencies were being maximized at every time point regardless of changes in the system. With these improvements, Strass was able to generate over 100 percent of its total energy needs on-site.[66]

Thus, without even adding additional waste streams, this facility demonstrated that WWTPs *can* generate enough electricity to be self sufficient. Were a facility like Strass were to add food waste, it could increase its methane generation potential by a factor of three.[67]

Essex Junction, Vermont

Facility Facts	
Design Flow	3.3 MGD
Average Flow	2.0 MGD
CHP System Type	2 x 30kW Microturbines
Percent of Total Energy Needs	37-39%

[65] "Case Study: Sustainable Treatment: Best Practices from the Strass in Zillertal Wastewater Treatment Plant." Water Environment Research Foundation. March 2010.

[66] "Case Study: Sustainable Treatment: Best Practices from the Strass in Zillertal Wastewater Treatment Plant." Water Environment Research Foundation. March 2010.

[67] Based on the findings of the EBMUD bench-scale study described in the previous case study.

Generated On-Site	
Total Capital Cost	$303,000

Closer to Massachusetts, the Village of Essex Junction in Vermont's WWTP is a small facility with 3.3MGD design flow and 2.5 MGD average flow. This case study is of special interest as nearly three-quarters of MA's 133 WWTPs fall below 5 MGD.[68] Monetary incentives were made available to this facility to help with the payback for this project; the sewer governing board required that payback be seven years or less. Essex Junction received $40,000 from Efficiency Vermont, $25,000 from Biomass Energy Resource Center, $10,000 from Native Energy for carbon credits, and $5,000 from the Department of Energy, Region 1 to ensure data collection and dissemination.[69]

With a willing manager to carry this initiative through, Essex Junction upgraded its digesters and added CHP and is continuing to innovate and explore ways to maximize the energy generation potential. At present this facility is already incorporating fats, oils and grease (FOG) and batch feeding high strength food waste.[70] Ultimately, Essex Junction not only demonstrates that AD and CHP can be effectively used at small WWTPs, it also possible to effectively incorporate additional waste streams into wastewater treatment, and a willing manager enables innovation and adaptation as technological advances emerge.

Gloversville-Johnstown, New York

Facility Facts	
Design Flow	13 MGD
Average Flow	6.5-7 MGD
CHP System Type	2 x 350kW engines
Percent of Total Energy Needs Generated On-Site	100% Anticipated
Total Capital Costs	$9.5M
Engine Generator Upgrade Cost	$3M

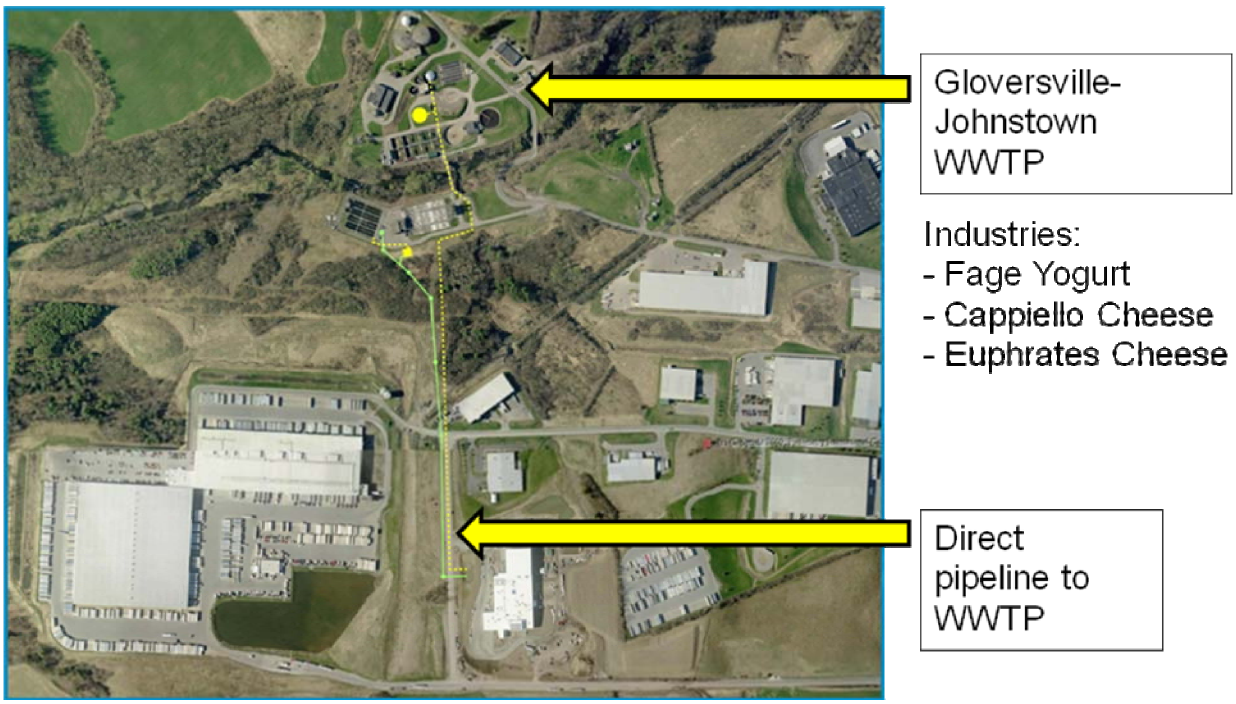
[68] "Massachusetts Facilities Online." Massachusetts Water Pollution Control Association. Web. <http://www.mwpca.org/mwpca3.htm>. Accessed February 23, 2010.

[69] Eaton, Gillian, Jutras, James L. "Turning Methane into Money: Cost-Effective Methane Co-Generation Using Microturbines at a Small Wastewater Plant."

[70] Personal communication with James Jutras of the Village of Essex Junction WWTP by Shutsu Wong. June 21, 2010.

The Gloversville-Johnstown, New York facility is a 13 MGD facility that utilized its excess capacity and proximity to dairy waste producers (yogurt and cheese plants) to integrate additional organic waste streams into it wastewater treatment processes for greater energy generation. In addition, at the time, the facility was struggling financially and needed to improve its wastewater treatment bottom line; the AD and CHP strategy of this facility enabled it to take control of its finances. [71] The following aerial view of the area immediately around the WWTP shows how the placement of industry enabled this partnership; the waste producers pay a lower rate for disposal directly to the digesters at the WWTP, and the WWTP increases its methane production and its onsite energy generation.

Figure 6: Johnstown Industrial Park and Connections to the WWTP[72]



Through NYSERDA funding, this facility is improving its digesters and biogas storage and is adding additional CHP capacity. At the completion of this project, the WWTP is anticipating electricity generation in excess of the facility's needs!

This case demonstrates how regional wastes can be incorporated into a wastewater treatment facility's waste management plan to not only reduce waste, but to tap the energy potential of both waste

[71] "Is it a Digester or a Power Plant? Anaerobic Digestion and CHP at the Gloversville-Johnstown Joint Wastewater Treatment Plant." Presented by Robert Ostapczuk, Malcom Pirnie. Northeast Residuals & Biosolids Conference. November 9, 2010.

[72] Aerial view extracted from: "Is it a Digester or a Power Plant? Anaerobic Digestion and CHP at the Gloversville-Johnstown Joint Wastewater Treatment Plant." Presented by Robert Ostapczuk, Malcom Pirnie. Northeast Residuals & Biosolids Conference. November 9, 2010.

streams. The example of the Gloversville-Johnstown WWTP suggests that potential synergies between industry and WWTPs can be an especially productive avenue to pursue for a region or community that is considering options to improve the cost effectiveness of adopting AD and CHP.

Nashua, New Hampshire

Facility Facts	
Design Flow	16 MGD
Average Flow	12 MGD
CHP System Type	370 kW reciprocating engine (currently operating at 120kw)
Percent of Total Energy Needs Generated On-Site	20%

Next is the case of Nashua, NH, where changes in the state landfilling policies and high sludge disposal costs motivated the facility to explore the possibility of using AD and CHP. Nashua's WWTP had formerly buried unstabilized biosolids at the city landfill. When that landfill was closed, the city was prohibited from burying unstabilized biosolids in the new landfill cell.[73] Funded with a $10 million bond, Nashua installed a 1.3 million gallon egg-shaped primary digester, secondary digester and congeneration facility to address these needs.[74]

AD, a biosolids stabilization process, enabled the facility to meet landfilling requirements while also reducing its disposal needs, reducing the truckloads from as many as 50 loads a week to 20.[75] Annual disposal costs were reduced by as much as one million dollars with digestion. In addition, the facility currently generates $250,000 of electricity a year, yielding annual savings of $750,000 from the combination of reduced disposal costs, electrical savings, operational improvements and payment of the loan.[76]

Considering the savings from disposal costs, the loan could be repaid within ten years. This case suggests that disposal alone can make an AD and CHP project attractive to a facility, given conditions such as high costs of disposal and limitations on disposal.

[73] "GHD Case Study: The Nashua anaerobic digester complex." GHD. William R. Hall, Project Director.

[74] "GHD Case Study: The Nashua anaerobic digester complex." GHD. William R. Hall, Project Director.

[75] "GHD Case Study: The Nashua anaerobic digester complex." GHD. William R. Hall, Project Director.

[76] "GHD Case Study: The Nashua anaerobic digester complex." GHD. William R. Hall, Project Director.

Sheboygan, Wisconsin

Facility Facts	
Design Flow	18.4 MGD
Average Flow	11.8 MGD
CHP System Type	10 x 30kw microturbines
Percent of Total Energy Needs Generated On-Site	35-50%
Cost of the cogeneration system	$1.2 M
Cost of system to Sheboygan	$200,000

The last case study of interest is Sheboygan, WI. Between the years of 2002 and 2008, the natural gas prices rose by 108 percent and electricity rates rose by 72 percent.[77] An onsite energy generation allowed the facility to insulate itself from those rising operational costs.

In a public-private partnership with Alliant Energy, the local power utility, Alliant Energy purchased and installed 10 microturbines while the WWTP purchased a heat recovery system, for a total $1.2M project cost, for which the WWTP was only responsible for $200,000. The WWTP purchases its power from the utility, and the power utility pays the WWTP to monitor the system, yielding a reduced energy cost for the WWTP. This partnership enabled a form of net metering. After six years, the WWTP will have the option of buying the mictroturbines from Alliant energy for $100,000, just 10 percent of the total investment by the utility.[78]

With the incorporation of high strength wastes, cheese processing waste in this case, the facility saw biogas production increase dramatically.[79] Similar to Gloversville-Johnstown, the industrial waste partnership provides lower cost waste disposal for the cheese processor while increasing both heat and electricity generation for the WWTP and Alliant Energy. The facility is now producing 35-50 percent of its energy needs onsite.[80]

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[77] Greer, Diane. "High-Strength Wastes Boost Biogas Production." Biocycle. March 2009, Vol. 50, No. 3, p. 41. <http://www.jgpress.com/archives/_free/001831.html>. Accessed on January 28, 2011.

[78] Greer, Diane. "High-Strength Wastes Boost Biogas Production." Biocycle. March 2009, Vol. 50, No. 3, p. 41. <http://www.jgpress.com/archives/_free/001831.html>. Accessed on January 28, 2011.

[79] Greer, Diane. "High-Strength Wastes Boost Biogas Production." Biocycle. March 2009, Vol. 50, No. 3, p. 41. <http://www.jgpress.com/archives/_free/001831.html>. Accessed on January 28, 2011.

[80] Personal communication with Dale Doerr, Superintendent of Sheboygan Regional WWTP, November 1, 2010

Sheboygan's experience demonstrates the potential of public-private partnerships, a system often called performance contracting, where the private sector purchases the equipment and there is a sharing of the equipment, operation and/or maintenance of the system. The enables facilities to avoid the initial costs of installation while still benefitting from the technology. Sheboygan took the public-private partnership one step further with the injection of high strength wastes into its digesters to boost biogas and methane production.

Elements of Success

To summarize the findings from the case studies, there were several key elements of success as well as certain combinations of conditions that motivated change at these facilities. Most notably, many of these facilities had limiting conditions that motivated exploration of AD and CHP. Those limitations included prohibitive disposal costs, insufficient disposal locations, organics bans, high energy costs and financial trouble.

The other most prominent condition was the recognition of the opportunities to be had and initiative to capitalize on those opportunities. EBMUD transformed its excess capacity into an opportunity to receive additional organic waste streams, helped the community comply with its local organics ban, and patented a food slurrying process to transform the ideas into a reality at the WWTP. Gloversville-Johnstown saw the opportunities to partner with dairy food processors and developed an industrial park with the infrastructure to feed their digesters high strength wastes to boost energy production. Strass determined efficiencies could be improved and developed plant staff and tools to achieve those efficiencies. Sheboygan received a unique offer for partnership with Alliant Energy and took it. Nashua saw meeting regulatory requirements to stabilize its sludge output as an opportunity to also reduce its disposal costs. Fairhaven's recognized the economic benefits of AD and CHP through its feasibility study and was already prepared to move forward by the time a funding opportunity presented itself. The list could continue on and on.

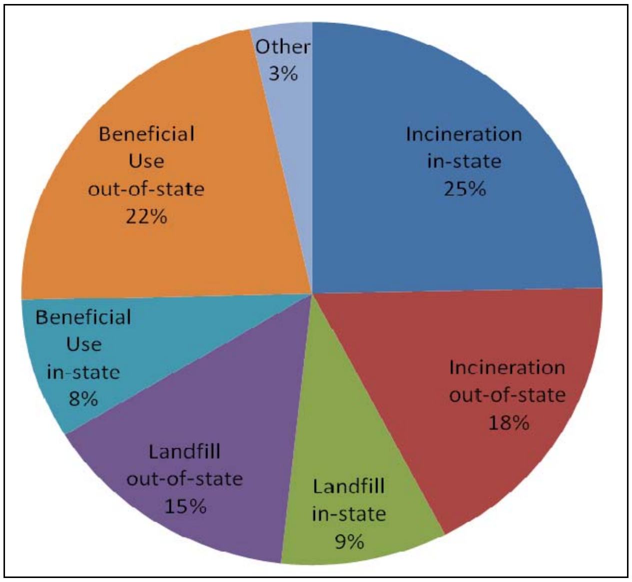
Ultimately, the core message of these studies is that AD and CHP present a wide range of economic, environmental and practical benefits and opportunities, and it is up to municipalities and facilities to capitalize upon the opportunities when they arise. These opportunities and benefits can often be created by local, state and regional programs, including initiatives that ban organics in landfills, establish moratoriums on waste combustion or set more stringent sludge stabilization requirements.

Biosolids Opportunities in MA

In light of all of this research, there is a clear message that these technologies present an opportunity for MA if the relevant players are willing to take hold of organic waste management at WWTPs. An effective waste to energy program is possible through targeting WWTPs, and AD and CHP are strong candidates for enabling such a program.

The following pie chart depicts how biosolids are currently managed in MA and demonstrates one facet of the untapped potential for energy generation through anaerobic digestion:

Figure 7: 2005-2006 Biosolids Use/Disposal in MA (dry tons/year)
Beneficial use quantities are based on sludge amounts.
Total MA Biosolids Produced: 176,700 dry tons per year.
Data Source: MA Biosolids Survey 2005-2006.



As of this 2005 to 2006 assessment, 67 percent of MA's biosolids, or 118,410 dry tons a year, are sent for either landfilling or incineration. While 30 percent is beneficially used, only eight percent of that is used within the state of MA. Clearly there are significant waste streams in MA that can be captured for energy generation, whether through AD or any other waste to energy technology.

Adding Additional Organic Waste Streams to WWTPs

In addition to municipal wastewater solids, other organic waste streams can be incorporated into the wastewater treatment process if a facility is utilizing AD. Not only is this beneficial for the breakdown of other organic solids, adding other organics such as food scraps has the potential to *enhance* the digestion process, improving volatile and total solids breakdown and increasing methane production potential.[81] This potential was demonstrated through the study by the East Bay Municipal Utility District in Oakland, California, an example that was explored in greater detail in the "Non-MA Case Studies" section.

The consideration of additional organic waste streams is important because these potential streams are significant components of the solid wastes that end up in landfills. The following table from the EPA Region 9 shows the breakdown of the solid wastes that end up in landfills:

[81] "Turning Food Waste into Energy at the East Bay Municipal Utility District: Investigating the Anaerobic Digestion Process to Recycle Post-Consumer Food Waste." East Bay Municipal Utility District.

Figure 8: Municipal Solid Waste Sent to Landfill, 2007[82]

Thus, beyond biosolids in MA, there are also significant streams of other solids wastes, of which food waste is a significant component. According to Region 9's pie chart, approximately 18 percent of our solid wastes are comprised of food waste. Given that food waste has the potential to generate three times more methane per ton as compared to biosolids,[83] tapping this additional organic waste stream with anaerobic digestion will provide significant benefits on multiple fronts – from the perspectives of solid waste management, greenhouse gas reduction and renewable energy generation.

So, to sum up the benefits, adding additional waste streams can increase the revenue potential, methane production and renewable energy production associated with the addition of anaerobic digesters and combined heat and power systems. Moreover, this strategy will enable MA to divert organic waste from landfills. All of these benefits will enable us to achieve other existing state goals, including the new 2010 Solid Waste Master Plan and other goals associated with reducing greenhouse gases and increasing use of renewable energy.

The Massachusetts Context

Given the strong case for the use of AD and CHP at municipal WWTPs to not only reduce their environmental impacts but to facilitate the reduced impact of state waste streams, this section

[82] "Turning Food Waste into Energy at the East Bay Municipal Utility District (EBMUD): Reducing Food Waste." U.S. EPA, Region 9: Waste Programs. <http://www.epa.gov/region9/waste/features/foodtoenergy/food-waste.html>. Accessed January 26, 2011.

[83] "Turning Food Waste into Energy at the East Bay Municipal Utility District: Investigating the Anaerobic Digestion Process to Recycle Post-Consumer Food Waste." East Bay Municipal Utility District.

identifies areas for intervention and looks forward to emerging ideas and strategies that may contribute to the most effective program possible for the state. A critical component of moving forward is the recognition of the context within which these opportunities lie to enable the best crafted strategy for capitalizing on those possibilities. Thus, this section intends to establish a sense of that framework, which includes a review existing state goals and initiatives that are relevant to AD and CHP.

Existing State Goals: Draft 2010-2020 Solid Waste Master Plan, Greenhouse Gas Emissions, Renewable and Alternative Portfolio Standards

Several aspects of environmental protection for the state of MA are relevant to this discussion of renewable energy generation at municipal WWTPs. Most notable is the Draft 2010-2020 Solid Waste Master Plan. The following table highlights the relevant goals and how an AD and CHP based program can enable MA to attain its solid waste goals for the next ten years.

Figure 9: Draft 2010-2020 Solid Waste Master Plan Goals and its Relevance to AD and CHP

Draft 2010-2020 Solid Waste Master Plan Goals & Focuses (extracted directly from the Plan)[84]	Goal relevance to AD and CHP
"Reduce solid waste disposal by 30% by 2020, from 6,550,000 tons of disposal in 2008 to 4,550,000 tons of disposal by 2020."	AD will help MA attain this goal. AD reduces the amount of residuals that need disposal from a WWTP. AD also enables the diversion of organic wastes from other disposal streams, breaking down the waste and thus reducing the volumes needing eventual disposal.
"By 2050, Massachusetts residents and businesses should reduce the amount of waste they produce by 80%, and virtually eliminate products containing toxic chemicals from our disposal facilities."	Again, the diversion of organic wastes to WWTPs can facilitate reaching this goal. For agricultural businesses, AD can reduce biosolids disposal volumes.
***"Eliminate Barriers to Siting Recycling and Composting Facilities* – Modify MassDEP's siting regulations to eliminate barriers to siting facilities that support increased recycling and composting, as well as other facilities such as anaerobic digestion facilities that generate energy from source separated organic materials. Maintain strict facility oversight to ensure a high level of environmental performance."**	Directly mentioned as a component of this goal, this initiative will facilitate the adoption of AD (and CHP where beneficial) and the development of new facilities to manage wastes using AD.
***"Maintain Moratorium on Municipal Waste Combustion* – Maintain the 1990 moratorium on expansion of municipal solid waste combustors. Additional capital intensive disposal facilities would result in fixed capacity for decades that would not be needed given this Plan's aggressive recycling goals and policies."**	With a moratorium on municipal waste combustion, municipalities will have to seek other means of waste disposal, especially if their waste streams increase. AD is one such option that municipalities can pursue.
"Work with interested parties (municipalities and/or businesses) to develop integrated solid waste	AD is a strong candidate for achieving integrated solid waste management systems, particularly as it is a

[84] "Draft Massachusetts 2010-2020 Solid Waste Master Plan: Pathway to Zero Waste." Massachusetts Department of Environmental Protection and Executive Office of Energy and Environmental Affairs. July 1, 2010.

management systems that achieve our objective of maximizing recycling and composting and minimizing residual materials in need of disposal."	process receptive to a wide range of organic waste streams including municipal wastewater solids, source separated organics, food processing wastes, etc.
"Pilot innovative approaches that achieve our objective of improving the environmental performance of solid waste facilities, can divert 100% of waste materials from disposal, and help achieve the goal of zero waste at a local and regional level."	While AD and CHP may not be the only options, they are strong contenders for improving the environmental performance of WWTPs, reducing waste volumes (AD not only reduces total solids, its byproduct can also be reused as a soil amendment) and ultimately helping the region attain its goal of zero waste.

Also relevant are efforts to reduce greenhouse gas emissions in the state and the continuing development of a state renewable energy credit program. The Global Warming Solutions Act requires that greenhouse gas emissions be reduced by 80 percent from 1990 levels by 2050 and by 10 to 25 percent by 2020.[85] Managing solid waste through AD and CHP can facilitate reaching the goals set forth by this act by reducing the amount of methane emissions that would otherwise be emitted during the breakdown of organic materials in wastewater sludge and other organics currently being digested aerobicly or being landfilled. Allowing these waste streams to be digested in a contained, anaerobic environment prevents the escape of methane to the atmosphere and productively consumes that methane (a gas 20 times more damaging than carbon dioxide in terms of heat capture within the atmosphere[86]) for renewable energy generation. The renewable energy itself also prevents greenhouse gas emissions by displacing other greenhouse gas emitting energy sources.

Lastly, Massachusetts has established a Renewable and Alternative Portfolio Standard (RPS and APS) program through the state Department of Energy Resources. These portfolio standards require that the state obtain its energy from a specified percentage of renewable and alternative sources, with these percentages growing annually.[87] As a consequence, electricity suppliers must purchase some portion of their energy from these sources. To do so, the New England Generation Information System (managed by NEPOOL) was established to track available renewable energy sources and the credits they produce trade and purchase.[88] Through this program, a market was generated for renewable energy and the credits associated with them. Consequently, the development of additional renewable energy sources at WWTPs through AD and CHP not only enables the state to achieve its standard, it also produces a

[85] "Draft Massachusetts 2010-2020 Solid Waste Master Plan: Pathway to Zero Waste." Massachusetts Department of Environmental Protection and Executive Office of Energy and Environmental Affairs. July 1, 2010.

[86] "Climate Change: Methane." Environmental Protection Agency. Web. Accessed January 31, 2011. <http://www.epa.gov/outreach/>.

[87] See: www.mass.gov/energy/rps for more information on renewable portfolio standards in MA.

[88] "Generation Information System (NE-GIS) and Renewable Energy Certificates (RECs)." Massachusetts Clean Energy Center. <http://www.masscec.com/index.cfm/cdid/11518/amp%3Bpid/11163>. Accessed November 17, 2010.

potential revenue stream for generating this energy beyond the creation of the energy itself, yet another reason for municipal facilities to consider these technologies.

Other MA Conditions

According to the SWMP, total landfill capacity of the state is also expected to decline; in 2009, there was just under two million tons available, and that capacity is expected to become around 600,000 tons by 2020, reducing total capacity by approximately 70 percent.[89] Reduced capacity presents a situation like that of Nashua, NH; landfill space becomes more valuable and costly, forcing municipalities to seek alternative disposal mechanisms to reduce those costs. This situation may also present a revenue generating opportunity for WWTPs to receive additional organic wastes at their facilities. In anticipation of this future, WWTPs have even more reason to consider AD as a part of their long-term waste management strategy.

The Private Sector

Looking beyond municipal WWTPs, the private sector is also adopting these technologies because of the financial benefits of doing so. While the focus of this study is the opportunities at municipal wastewater facilities, the private sector is another area to consider when crafting regulations and programs for a waste to energy program and has the potential to be a component of a more comprehensive state-wide plan. In addition, as highlighted earlier, public-private partnerships often enable the public sector to take steps that would otherwise be too costly or difficult to do.

One example is the Rutland Farms project by the MA Dairy Energy Group that received a draft Determination of Need permit through the solid waste management program in 2010. These five farms are working with AGreen Energy, LLC to develop anaerobic digesters for manure and source-separated organics. This small facility will generate electricity for use at Jordan Dairy farms and will produce a liquid fertilizer from the supernatant of the anaerobic digestion process. They are partnering with Casella Waste Systems to determine the best strategy for collecting, transporting and processing source-separated organics that will be brought to the facility. Through these partnerships, this collection of five farms is taking strides to capture the available energy in their existing waste streams.

Other Linkages

Thinking beyond the incorporation of multiple waste streams for an integrated waste management plan, a waste to energy program can expand even farther to include the state power generation system. The Los Angeles Department of Water and Power has developed a partnership between two of its facilities; the Hyperion Wastewater Treatment Plant sends its biogas by pipeline to the Scattergood Steam Power Plant for power generation. Thinking more regionally, this system has enabled resource recovery while minimizing the infrastructure duplication across sectors. While similar to the industrial park setup at

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[89] "Draft Massachusetts 2010-2020 Solid Waste Master Plan: Pathway to Zero Waste." Massachusetts Department of Environmental Protection and Executive Office of Energy and Environmental Affairs. July 1, 2010.

Gloversville-Johnstown, Hyperion uses its proximity to a power plant for the most direct means of transfer. Both systems link across sectors and avoid unnecessary redundancy in wastewater treatment equipment (Gloversville-Johnstown) and in power generation equipment (Los Angeles). These types of linkages should also be explored for Massachusetts to maximize efforts while cutting back on redundancy, especially in light of limited municipal budgets.

In light of all of this research, there are clear opportunities in MA to develop an effective waste to energy program through encouraging WWTPs to adopt AD and CHP. A review of existing state goals reveals that there are opportunities to achieve multiple goals simultaneously through a waste to energy program focused on municipal WWTPs. Linking multiple waste streams from a regional or state-wide perspective can enable maximum impact in any state actions, but further study will be necessary determine the optimal strategy for doing so.

Conclusion

Massachusetts has the opportunity to be a leader in New England in its management of waste systems, especially if it begins to think more broadly about its waste streams. This study argues for the use of AD and CHP, technologies that are known to be effective in renewable energy generation. To push the envelope and truly be a leader, the state can take strides to do more than just that; Massachusetts has the opportunity to view its waste systems holistically, to see where those systems overlap and through regional solutions, adopt a vision of resource recovery, where more is reclaimed and less is wasted.

With millions of gallons of wastewater passing through the plants each day, the opportunity costs of foregoing this renewable energy source are growing as we delay action on adopting these technologies. These costs are both environmental and economic; AD and CHP minimize emissions from energy generation and wastewater processing which generating positive cash flow for WWTPs. States like California and New York are already ahead of the domestic curve in adopting these practices, a place where Massachusetts can also be if steps are taken to enable resource reclamation at its WWTPs. The possibilities of AD and CHP are proven, not only in the United States, but also abroad where AD and CHP have already taken root and are far more widely accepted and adopted. While there are veritable challenges in translating these ideals into reality, the grand vision of Massachusetts as a leader in resource reclamation in the North East is not beyond attainment as long as we, as a state, choose to take strides in the right direction.

We must identify key projects today and offer them the financial means to demonstrate the future of renewable energy, wastewater treatment and resource recovery. In doing so, Massachusetts can spark the transformation of New England's waste systems into an environmentally sound and economically stable network, helping bridge the gap where our nation falls short of global action to mitigate human environmental impacts.

Appendix A: Resources for Implementation

The study of AD and CHP, its impacts, the scientific backing for its benefits, and the experience of other facilities are continually growing and evolving. Thus, while this discussion has attempted to gather as much information as possible into one place, much more exploration is not only possible but necessary to tailor a program for the state and individual facilities. In this section, potential resources have been gathered for further investigation, keeping in mind that new studies and reports are continually emerging as acceptance and excitement grows around the idea of using WWTPs as opportunities for renewable energy and organic waste management.

Steps for Adopting AD and CHP

Initial steps for adopting AD and CHP include initial feasibility studies. In the case of Pittsfield WWTP, the plant was able to acquire an initial grant from the Massachusetts Technology Collaborative (MTC) to fund a feasibility study with SEA Consultants.[90] While not all plants may be able to acquire such grants (feasibilities studies, while considered low cost as compared to later steps in the process, cost in the order of tens of thousands), other programs exist for demonstrating the potentials of a new combined heat and power system. For example, the Northeast Combined Heat and Power Application Center conducts audits for plants that already have AD. The audit helps plants understand cost and energy saving potential of CHP system for their particular treatment plant. Furthermore, private firms that provide AD technologies to plants may also provide free initial budgetary studies; ADI Systems, Inc. suggested that they would be willing to provide municipalities a free budgetary proposal.[91] These initial assessments at no cost to the plant can help plants make the best educated decisions for the viability of these technologies at their specific plant. While the challenges of upfront costs often preclude consideration, these feasibility studies can enable facilities to explore the financial *benefits* of investing in AD and CHP systems that may outweigh the installation costs. For example, the initial feasibility study in Fairhaven, MA, which was only a fraction of the installation cost, demonstrated the financial benefits for the community before any commitment was made for its construction.

A critical component of the adoption process is the buy-in of plant operators, local decision makers and the community. Plant operators are responsible for carrying out the new processes and maintaining the new systems, and their support for these technologies is essential to bring about successful implementation. As mentioned earlier, past history of challenging AD systems in the 1980s has fostered a predisposition against these technologies, a significant hurdle that must be addressed. In Utah, through the Intermountain Application Center, plants have had the opportunity to learn more about these technologies. Through these training sessions, several facilities have elected to explore the

[90] Phone interview with Al Wells by Shutsu Wong. June 2010.

[91] Contact Scott Christian at ADI Systems, Inc. at 1-800-561-2831.

possibility of CHP at their facilities.[92] Other suggestions have included the development of some form of state-wide technical assistance or help desk type system to facilitate learning, training and troubleshooting.

Even more important than the plant operators is the acceptance of AD and CHP by local governing bodies. In order for facilities to obtain new infrastructure, the local community must see the value of these technologies and choose to acquire the necessary equipment. Furthermore, any financial support or financing decisions must pass through local decision makers. Thus, without local community and decision maker buy-in, even with plant operator support, anaerobic digestion and combined heat and power cannot become a reality.

Potential AD and CHP Initiative Strategies

Through all of the communications with practitioners in the field, ranging from WWTP operators themselves to federally funded regional assistance centers, many recommendations emerged for a strategic approach for state efforts. From the collection of those suggestions and from the picture of the state of AD and CHP applications in municipal WWTPs, this study has yielded several strategies that may be effective in reaching out to potential adopters of AD and CHP.

Plants that already have AD or are in the process of building new systems ought to be the first target. These plants would require the smallest capital investments to achieve on-site renewable energy generation, as they already have existing AD systems, or because they are already redesigning and reconstructing the facility. While some plants, like the Clinton WWTP, may not process enough wastewater to maintain a cost-effective CHP system, other larger plants like the Greater Lawrence Sanitary Sewer District have not assessed the viability of adding CHP to their existing system.

Focus on plants for which the addition of AD would produce sufficient biogas year round to support a CHP system. These plants are generally larger and can achieve greater economies of scale when installing AD and CHP systems.[93] Furthermore, as the larger plants process higher volumes of wastewater, there is also greater environmental benefit achieved through these larger projects as compared to the smaller projects.

For smaller plants, the most effective setup for renewable energy may be for AD alone, where all of the biogas can be reused on-site for most of the year. This approach would reduce the size of the projects that are recommended and would perhaps make them more financially feasible. As shown by the Clinton WWTP, below a certain size, installing a CHP system may have a very long payback timeline as excess gas is only seasonal in the cold New England climate. However, consideration of other organic

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[92] Personal communication with Christine Brinker of Intermountain CHP Application Center by Shutsu Wong. June 22, 2010.

[93] Personal communication with Tom Broderick of Intermountain CHP Application Center by Shutsu Wong on June 17, 2010.

waste streams can boost methane production potential and make these facilities good candidates for AD and CHP systems despite their small size; Essex Junction is a good example of such a case.

Overall, WWTPs are an opportune target as many are already set apart from the communities and thus have greater flexibility for the addition of digesters and CHP technology. Furthermore, as these facilities are designed and permitted to manage wastewater and discharge particular effluents, municipal WWTPs are also opportunities for the insertion of additional organic wastes for higher rates of biogas and renewable energy generation.

Innovative Water to Energy Solutions

As the adoption of AD and CHP at WWTPs is no easy task, several other potential means of tapping the energy contained within wastewater are worth noting. One especially innovative solution is the use of microbial fuel cells to directly harvest energy from raw waste. IntAct labs and several other startups are in the process of developing this technology for applications such as municipal wastewater treatment.[94] Other options include the mixing of sludge into landfill trash to catalyze methane production for capture. Springfield WWTP is currently sending their sludge to landfill, where the gas is capture and reused. Unfortunately, this system is not as efficient for the production and capture of biogas.

Regional facilities are another alternative that may be more feasible, particularly for space constrained facilities. Furthermore, a regional facility can be much larger and have greater economies of scale during the installation of AD and CHP. The downside is that plants would have to continue transporting their sludge for treatment, limiting the financial benefit of each facility. At the same time, the operational changes and challenges would be limited to this facility, and the capital costs can be shared or financed by a larger entity such as the state.

As mentioned previously, the addition of high strength food wastes can also improve the productivity of an AD and CHP system. If AD and CHP systems are more productive, the payback on the installation of these systems can be shortened, making the adoption of AD and CHP more financially feasible, even for smaller plants. While still considered relatively new, the case studies included in this report demonstrate that food wastes *can* be effectively incorporated into wastewater treatment systems to enhance methane (and renewable energy) production.

Lastly, selecting a single plant as a pilot project may help demonstrate the effectiveness of AD and CHP technologies. This plant may subsequently provide operational lessons to interested plants, enabling risk-averse operators to overcome fears of unknown processes and skepticism about their viability. Doing so will also enable the testing of new ideas such as the addition of high strength food wastes.

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[94] "The 50 Best Inventions of 2009: The Electric Microbe." TIME Magazine. November 12, 2009. <http://www.time.com/time/specials/packages/article/0,28804,1934027_1934003_1933965,00.html>. Accessed January 21, 2010.

Mapping Massachusetts: A Potential Approach

In the following maps of MA, information regarding the distribution of digesters, WWTPs, food waste generators and other biosolids generators has been gathered to depict a graphical and geographical means of assessing the best opportunities for intervention. This mapping project is only a sample approach for how facilities and places can be selected for pilot projects or special attention as part of an AD and CHP initiative.

Figure 10: The Distribution of Anaerobic Digesters in MA

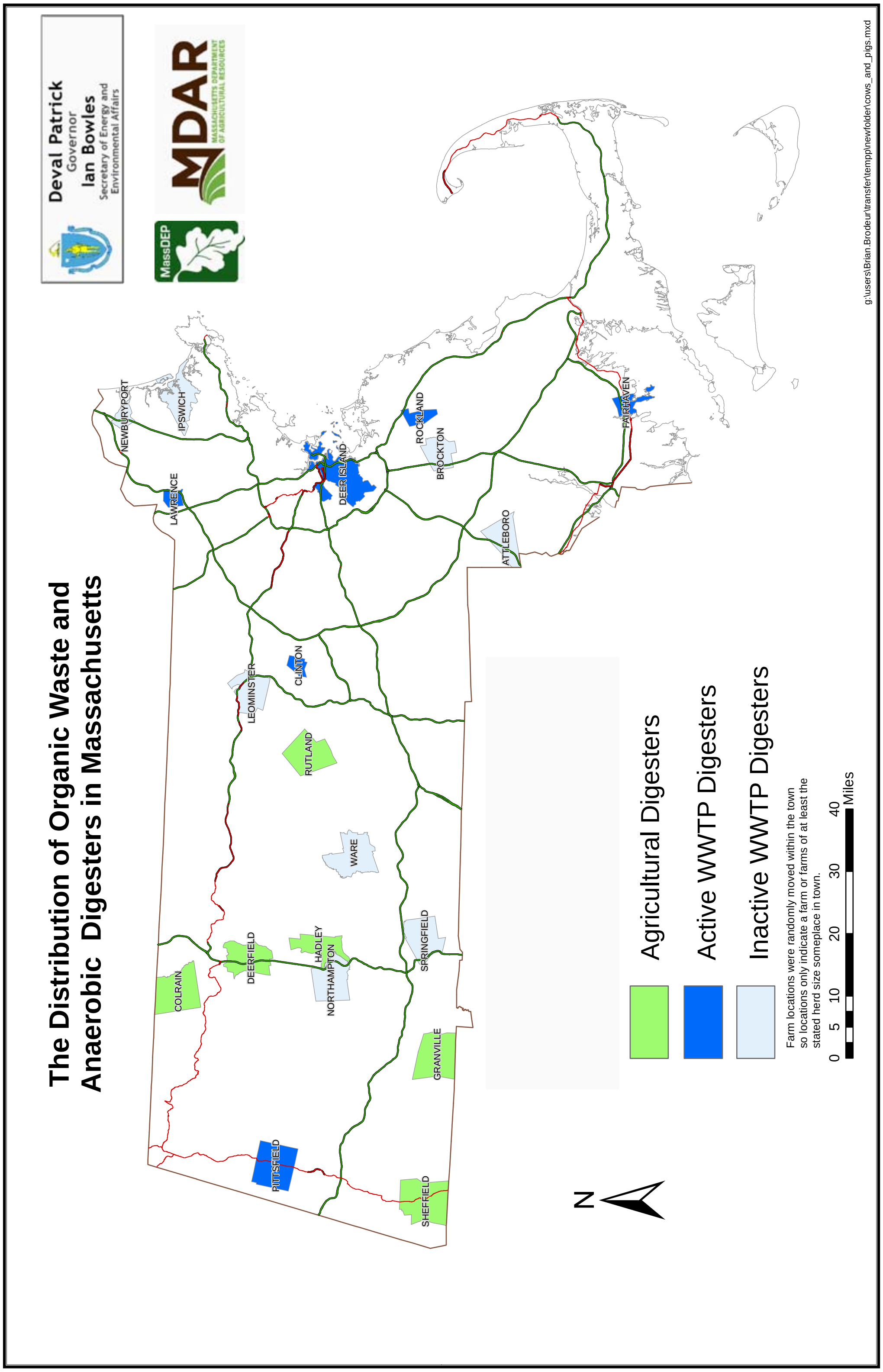


Figure 11: The Distribution of Anaerobic Digesters and Food Waste Generators in MA

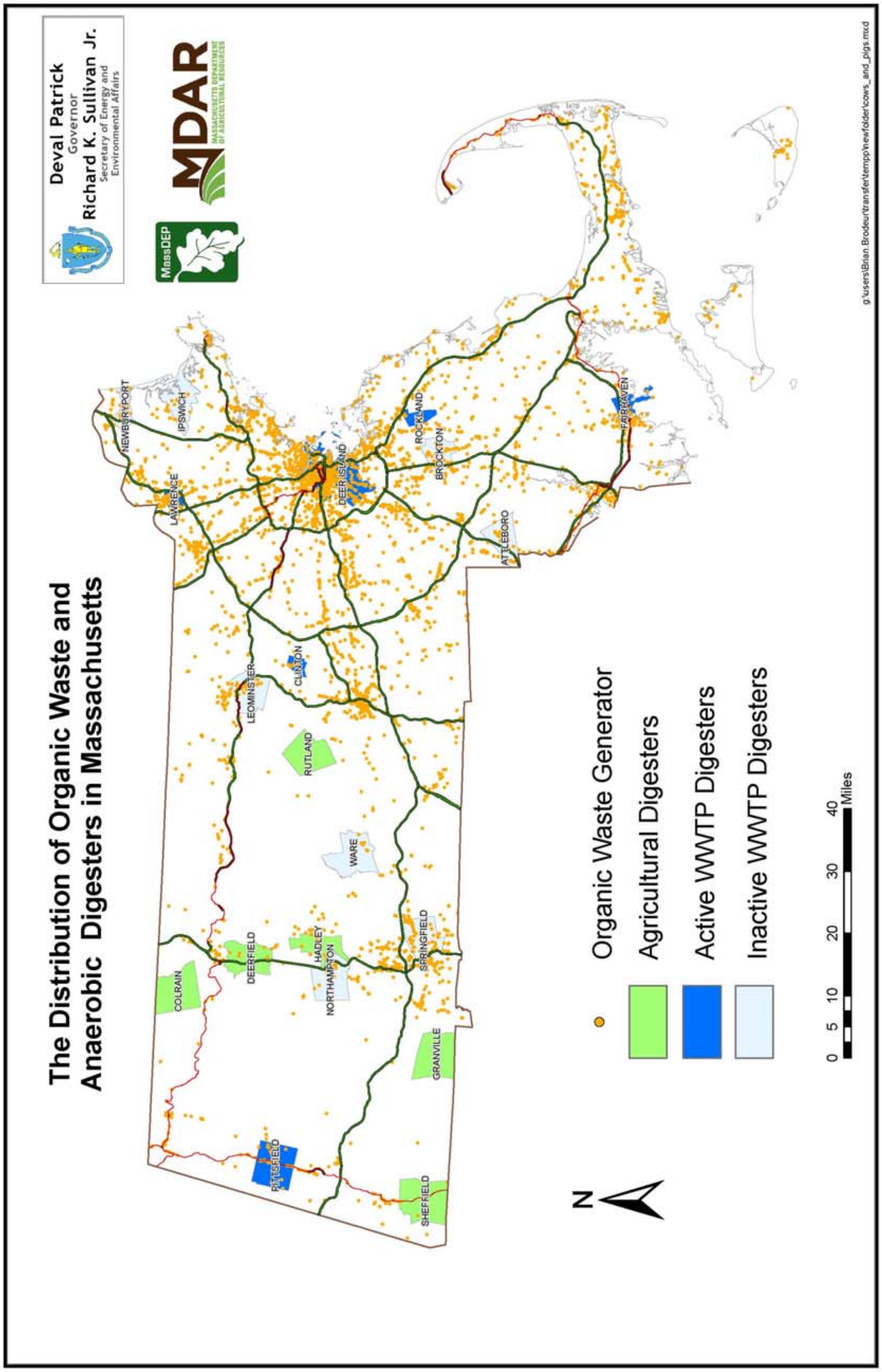
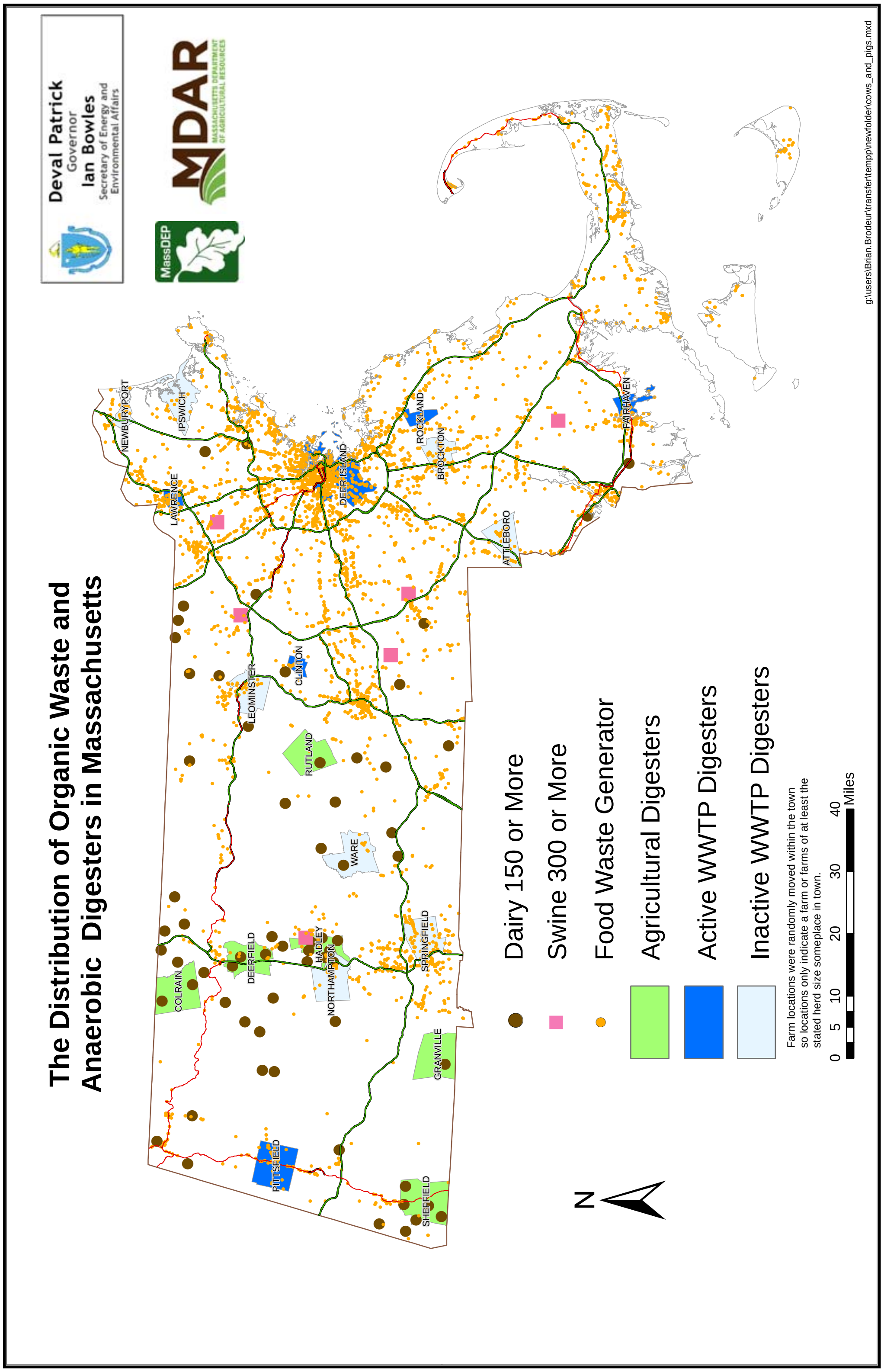


Figure 12: The Distribution of Organic Waste and Anaerobic Digesters in MA



Appendix B: Additional Resources

Additional resources are listed in this section for further study and exploration:

- Draft 2010-2020 Solid Waste Master Plan: A Path to Zero Waste (http://www.mass.gov/dep/recycle/priorities/dswmpu01.htm)
- MA Green Communities Grant Program (http://www.mass.gov/?pageID=eoeeaterminal&L=3&L0=Home&L1=Energy,+Utilities+&+Clean+Technologies&L2=Green+Communities&sid=Eoeea&b=terminalcontent&f=doer_green_communities_gc-grant-program&csid=Eoeea)
- MA Sustainable Development Initiative
- Global Warming Solutions Act (http://www.mass.gov/dep/air/climate/gwsa_docs.htm)
- Mapping of Food Waste and Food Waste Generators in MA
    - Composting Facilities - http://www.mass.gov/dep/recycle/reduce/composti.htm,
    - Food Waste Generators Map - http://www.mass.gov/dep/recycle/priorities/foodmap.htm
- MA DEP Wastewater Treatment Plants Website (http://www.mass.gov/dep/water/wastewater/wwtps.htm)
- MA Water Pollution Control Association – List of WWTPs (http://www.mwpca.org/mwpca3.htm)
- New England Interstate Water Pollution Control Commission – Wastewater Operator Database (http://www.neiwpcc.org/wastewater/search.asp)
- Northeast Combined Heat and Power Application Center (provides initial assessments) (http://www.northeastchp.org/nac/)
- Massachusetts Clean Energy Center (has provided grants for feasibility studies in the past) (http://www.masscec.com/)
- Environmental Protection Agency CHP Partnership (provides technical assistance to candidate sites) (http://www.epa.gov/chp/)
- Additional Funding Opportunities:
    - 2009 ARRA Funding for Clean Water and Drinking Water State Revolving Funds (http://water.epa.gov/aboutow/eparecovery/index.cfm),
    - Energy Policy Act of 2005 (http://lpo.energy.gov/wp-content/uploads/2010/09/EPAof2005.pdf),

- Energy Independence and Security Act of 2007 (http://energy.senate.gov/public/_files/RL342941.pdf),
- National Grid CHP Incentive (http://www.nationalgridus.com/masselectric/a3-1_news2.asp?document=4853)
- Report: "Evaluation of Combined Heat and Power Technologies for Wastewater Treatment Facilities." Columbus Water Works, prepared by Brown & Caldwell. December 2010. (http://www.cwwga.org/pdf/CHP_Technologies_prelim%5B1%5D.pdf)

Appendix C: Tables of Case Studies

Facilities with Operating Digesters

Plant Name	Phone Number	Average Flow (MGD)	Design Flow (MGD)	AD System	Current Use of Biogas	CHP System Type
Deer Island Sewage Treatment Plant (MWRA)	David Duest, (617)660-7870 x7870	436	1270	in use	CHP	steam turbine/boiler
Pittsfield Wastewater Treatment Facility	Thomas Landry, (413) 499-9304	12	17	in use	CHP	microturbines
Fairhaven Waste Pollution Control Facility	Bill Fitzgerald, (508) 979-4032	2.7	5	in use	CHP	reciprocating engine
Clinton Wastewater Treatment Plant (MWRA)	John Riccio, (978)365-6144	2.4	3.01	in use	Boiler for heating / flare	no CHP
Rockland Wastewater Treatment Plant	Tony Olivadesa, (781)878-1863	2.5	2.5	in use	Boiler for heating / flare	no CHP
Greater Lawrence Sanitary District	Richard Hogan, (978)685-1612	31	52	in use	Burned to make sludge pellets for incineration	no CHP

Facilities with Non-operating Digesters

Plant Name	Phone Number	Average Flow (MGD)	Design Flow (MGD)	AD System Type	Current Use of Biogas	CHP System Type
Springfield Regional Wastewater Treatment System	Doug Bogardi (413) 787-6256 x 150	43	67	offline	N/A	N/A
Brockton Wastewater Treatment Plant	Meagan Faria, (508) 580-7885	17*	18	offline	N/A	N/A
Leominster Wastewater Treatment Plant	Robert Chalifax, (978)537-5720	5-6	9.3	offline	N/A	N/A
Attleboro Wastewater Treatment Plant	Paul Kennedy, (774) 203-1820	4	8.6	offline	N/A	N/A
Northampton Wastewater Treatment Facility	George Brehm, (413)587-1092	3.5-4	8.6	offline	N/A	N/A
Newburyport Wastewater Pollution Control Facility	Joseph Dugan, (978) 465-4422	2.6	3.4	offline	N/A	N/A
Ipswich Wastewater Treatment Plant	Patrick Brennan, (978)356-6642	1.1	1.8	offline	N/A	N/A
Ware Wastewater Treatment Plant	Robert Gerulaitis (413)967-9624	0.817	2	offline	N/A	N/A

Plant Name	Average Flow (MGD)	Design Flow (MGD)	AD System Type	CHP System Type	Estimated Annual Cost Savings ($)*	Estimated Annual Cost Savings (%)**	Estimated AD and/or CHP System Cost ***	Payback Time (years)	Contact Person	Notes	References
Essex Junction WWTP (VT)	2.0	3.3		2 x 30kW microturbines	$37,000	37-39%	$303,000	6.8	James Jutras, WW@essexjunction.org		"Turning Methane into Money:Cost-Effective Methane Co-Generation Using Microturbines at a Small Waste Water Plant", Gillian Eaton,Vermont Energy Investment Corporation; James J. Lutras, Village of Essex Junction, Vermont; http://www.northeastchp.org/uploads/Essex%20Junction%20Project%20Profile.pdf
Pittsfield WWTP (MA)	12.0	17.0		3 x 65kW microturbines	$206,000	30%	$1,670,000	5 to 8	Tom Landry, (413) 499-9304, tlandry@pittsfieldch.com	MTC Funded Feasibility Study, Room for 4th turbine, explored possibility of accepting regional sludge, $45,000 a year in REC's	"City of Pittsfield Feasibility Study." SEA Consultants, Inc. April 1, 2008.
Fairhaven WWTP (MA)	2.7	5.0	2-stage, mesophilic	110 kW internal combustion engine	$330,100	36%	$7,200,000	13	Bill Fitzgerald, (508)979-4030	will accept FOG (fats, oils and grease), online May 2011, will also potentially accept other feedstock from its region	"Town of Fairhaven Anaerobic Digestion and Combined Heat and Power Feasibility Study." Brown and Caldwell. December 19, 2008.
Deer Island WWTP (MA)	365.0	1270.0	egg-shaped, mesophilic	115 MMBTU boiler + 3.28 MW steam turbine	$14,067,064 (FY09)	18%	$318.2M (AD) + $90M (CHP)	N/A	David Duest, 617-660-7870, Daniel O'Brien, Dan.Obrien@mwra.state.ma.us	Was able to sell bonds and get federal and state assistance	"DITP FY10 Key Ops Data.pdf" provided by David Duest; Personal Communications with David Duest by Shutsu Chai on March 4, 2010.
Columbia Boulevard WWTP (Portland, OR)	80-90	200.0		200kW fuel cell (no longer operating) + 4 x 30kW microturbines	$60,000 (fuel cell) + $70-80,000 (microturbines)		$1,300,000 (fuel cell + AD), $340,000 (microturbines)		Duane Sanger, (503) 823-2400	Fuel cell was not cost effective to repair as compared to microturbines	http://www.portlandonline.com/bes/index.cfm?a=40645&c=51142; http://www.chpcenternw.org/NwChpDocs/ColumbiaBlvdWastewaterCaseStudyFinal.pdf
Gloverville and Johnstown WWTP (NY)	6.5-7.0	13.0	2-stage	2 x 150kW internal combustion engines, 350kW generators (unclear whether this will replace the old 150kW engines)	$273,000	100% anticipated	$9,500,000	N/A	George Bevington, (518) 762-3101	4.5 million kW to operate, plant will hopefully generate 5.5 million kW -- can therefore sell back to grid excess! Plant takes dairy waste which uses half of the digester capacity, large dairy/trucked waste input	http://www.epa.gov/chp/documents/wbnr012110_bevington.pdf; http://www.nyserda.org/programs/Environment/G-T%20WWTF.pdf
Rochester Reclamation Plant (MN)		23.9	2 continuous mix digesters	2 x 1000kW Waukesha engines (internal combustion)	$564,398 (2007)		$4,000,000		Chet Welle, (507) 328-2400		http://www.chpcentermw.org/rac_profiles/Midwest/RochesterWWT.pdf
East Bay Municipal Utility District	75.0	168 (415 peaks manageable)	mesophilic	3 x 2.15 MW engine generators	$1,700,000	90%	multiple repeated investments	N/A	Vince De Lange, Biosolids Management Program Coordinator, vdelange@ebmud.com or (510) 287-1141	accepts food waste to use excess capacity - Trucked Waste Program (Resource Recovery)	http://www.ebmud.com/; http://www.ebmud.com/sites/default/files/pdfs/2009_Biosolids_Performance_Report.pdf; http://www.epa.gov/region9/waste/features/foodtoenergy/; http://www.energy.ca.gov/process/pubs/ebmud.pdf
Strass in Zillertal, Austria	5.0	10.0	two-stage	340 kW co-generation engine		100% onsite energy generation				system optimized through increased efficiencies, a highly educated work force and advanced process analysis tools	"Case Study: Sustainable Treatment: Best Practices from the Strass in Zillertal Wastewater Treatment Plant." Water Environment Research Foundation. March 2010.
Nashua, New Hampshire WWTP	12.0	16.0	egg-shaped digester	370 kW reciprocating engine	$750,000		$9,700,000	10	William Hall, GHD Principal, Bill.HallJr@ghd.com		"GHD Case Study: The Nashua anaerobic digester complex." GHD. William R. Hall, Project Director.
Sheboygan, Wisconsin WWTP	11.8	12.4		10 x 30kW microturbines			$1,400,000 ($200,000 paid by WWTP)		Dale Doerr [Daled@SheboyganWWTP.com	achieved through a partnership with Alliant Energy who paid for $1.2M of the project	Greer, Diane. "High-Strength Wastes Boost Biogas Production." Biocycle. March 2009, Vol. 50, No. 3, p. 41. <http://www.jgpress.com/archives/_free/001831.html>. Accessed on January 28, 2011.

Appendix D: Anaerobic Digestion Systems

The process of AD is driven by microorganisms which breakdown organic materials in the absence of oxygen. These microorganisms, anaerobic bacteria, which naturally occur in sewage, begin breaking down the organic materials in wastewater even before they reach the treatment plant. The process of "digestion" by the bacteria occurs in three stages, by three different types of bacteria.[95] In the first stage, hydrolytic bacteria convert complex organic wastes into sugars and amino acids. From these products, fementative bacteria form organic acids. Using these acids, acidogenic microorganisms form hydrogen, carbon dioxide and acetate, and finally, biogas, comprised mostly of methane and carbon dioxide, is formed by methanogenic bacteria.[96] Depending on the feedstock, or in other words, the source of the dewatered sludge, this gas can also contain other trace combustible and non-combustible gases in addition to contaminants such as water, siloxanes and hydrogen sulfides.[97] These contaminants can be corrosive and require removal before use with CHP systems.

Aside from the biogas itself, the digestion process leaves two other byproducts. The remaining solids, also called the digestate, are comprised of the materials not digested by the bacteria. This material can be nutrient rich and is usable as a fertilizer. For example, the solid digestate from Deer Island WWTP is processed and resold as fertilizer. In addition to the solid materials, the liquid effluent that remains after digestion can also contain nutrients; if toxic content is at acceptable levels, that effluent can also be used as a fertilizer.

In order to manage these processes within a digester at a WWTP, the digester must be airtight and maintain certain temperatures depending on the bacteria type. All digesters operate at a minimum of 68 degrees Fahrenheit to encourage bacterial activity, and the optimal operating temperature differentiates the two types of digestion processes. Mesophilic (middle temperature) digestion occurs around 98 degrees Fahrenheit. Thermophilic (high temperature) digestion occurs at higher temperatures. As compared to the mesophilic process, thermophilic digestion has a shorter total digestion time, allowing digestion tank volumes to be significantly smaller; both of these characteristics are preferable at WWTPs as it reduces the land area necessary to house the digesters. Unfortunately, fewer types of bacteria thrive in these high temperatures, and those that do are more sensitive to temperature fluctuations, making the digestion process more difficult to manage and maintain.

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[95] "Energy Savers: How Anaerobic Digestion (Methane Recovery) Works." U.S. Department of Energy: Energy Efficiency and Renewable Energy. June 14, 2010. <http://www.energysavers.gov/your_workplace/farms_ranches/index.cfm/mytopic=30003>.

[96] "BioEnergy in Oregon: Biogas Technology." Oregon.gov. June 14, 2010. <http://www.oregon.gov/ENERGY/RENEW/Biomass/biogas.shtml>.

[97] "Biomass Combined Heat and Power Catalog of Technologies." U.S. Department of Environmental Protection Combined Heat and Power Partnership. September 2007.

Mesophilic bacteria types are more abundant and can survive greater environmental disturbances. Consequently, mesophilic processes are more prevalent in WWTP applications.

Furthermore, AD includes a wide range of technologies, from egg-shaped digesters (which can be seen at Deer Island) to membrane bioreactors (such as that by ADI Systems, Inc.). In addition, the mixing technologies can also vary depending on the digester shape and size, from mechanical mixing to sludge reinjection.[98] The exact digester type and system that is most appropriate for a given WWTP will vary from case to case and is determined through the design process once a plant chooses to incorporate AD into its treatment process.

Technological Advances in AD

Advancements in AD technologies range in their application from the digesters themselves to the management of the digesters. This section provides a snapshot of the types of advances that are emerging, many of which are more developed and better tested internationally. (North America currently lags behind places like Europe and Australia in the adoption of AD and CHP, and many examples of successful implementation can be easily found abroad.) This progress includes the development of entirely new digestion technologies like the anaerobic membrane bioreactor to improvements in the management of buildup within pipes leading to and from digesters. Increasingly automated controls for AD systems have also facilitated their use. The ultimate usefulness of these developments varies from case to case.

The anaerobic membrane bioreactor (ADI-AnMBR) was developed by ADI Systems, Inc. with Kubota Corporation for wastewater treatment (as compared to a sludge process that occurs at a municipal WWTP). This technology employs membranes that are directly submerged into wastewaters and produces effluent that is has virtually no suspended solids and is far cleaner than typical digestion effluents.[99] ADI-AnMBR has been used successfully in Marlborough, MA at the Kens' Food manufacturing plant. Two primary advantages of the ADI-AnMBR system set it apart from conventional AD systems. First, its footprint can has potential to be dramatically smaller, requiring less space at an existing treatment plant. Second, these membranes are inserted directly into wastewater, eliminating the dewatering process while effectively treating the water. In addition, the digestion process time is shortened because of higher digestion rates. ADI-AnMBR has primarily been applied in industrial food waste settings with lower flow volumes and higher organic content concentrations, also known as high strength organic content waste water or high strength food waste.[100]

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[98] Phone call with David Duest of MWRA, Manager of Process Control at Deer Island Wastewater Treatment Plant. March 10, 2010.

[99] "Ken's Foods Utilizes Anaerobic Membrane Bioreactor to Generate Biogas to Power Wastewater Treatment Plant Operations." April 13, 2009. *Grainnet*. Accessed June 15, 2010 from http://www.grainnet.com/article.php?ID=74034.

[100] Personal communication with Scott Christian at ADI Systems, Inc. by Shutsu Wong. June 15, 2010.

While AD systems have potential to be smaller, as shown by ADI Systems, the volumes of wastewater that must be treated and the length of time that wastewater must remain within a digester constrains how small digesters can become. And, ultimately, ADI-AnMBR is applied directly to the wastewater unlike traditional AD that is applied to dewatered sludge. Thus, advances in size are limited; as Alan Wells of SEA Consultants articulated, "Volume is volume."[101] Digesters have to be designed to hold the amount of dewatered sludge that passes through a plant until the sludge has been digested, and the AD technology cannot modify the amount of holding space necessary.

The development of technologies to address challenges posed by the use of AD gas has also facilitated the adoptability of AD. Most notably, as AD gas is not pure methane like natural gas from the pipeline, the fuel gas must be conditioned before it can be used effectively in a CHP system. Technological advances for drying digester gas to prevent water condensation, the use of backup fuels to minimize the impact of inconsistent flow rates of digester gas, and carbon filters to limit silicon dioxide buildups are all components of the process that have been refined, enabling better efficiencies for installed systems.[102] Strategies for managing struvite buildup in pipes leading two and from digesters have also improved the function and efficiency of digesters and their associated systems.

Two new strategies for increasing the methane productivity of the AD process are *ultrasonic cell bursting* (a method of enhanced cell lysis) and the use of *carbon additives*. SEA Consultants, a Cambridge based consulting and engineering firm, explored the use of ultrasonic cell bursting for the Pittsfield WWTP. According to their feasibility study for Pittsfield, ultrasonic cell bursting is an emerging technology that destroys a greater amount of volatile organic solids, therefore making more organic material available for digestion and subsequent biogas production.[103] With the appropriate combination of nutrients, the addition of carbon can also enhance digestion, according to James Jutras, Water Quality Superintendent of the Village of Essex Junction WWTP in Vermont.[104] While literature supporting this new practice is lagging, success in practice at Essex Junction supports this claim.[105]

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[101] Personal communication with Alan Wells of SEA Consultants by Shutsu Wong. June 11, 2010.

[102] "Combined Heat and Power Market Potential for Opportunity Fuels." (2004). Resource Dynamics Corporation.

[103] "City of Pittsfield: Feasibility Study – Wastewater Treatment Plant." April 1, 2008. SEA Consultants, Inc.

[104] Personal communication with James Jutras, Water Quality Superintendent at the Village of Essex Junction WWTP in Vermont, by Shutsu Wong. June 22, 2010.

[105] Personal communication with James Jutras, Water Quality Superintendent at the Village of Essex Junction WWTP in Vermont, by Shutsu Wong. June 22, 2010.

Appendix E: Combined Heat and Power System Types

Gas turbines, which range from 500kW to 250MW, operate using the expansion of compressed air that moves the turbine blades, which subsequently produce electricity.[106] Fuel is mixed with compressed air and ignited. As that air expands from the heat generated by the ignited fuel, the air directed through the turbine blades. The mechanical power from the rotation of the turbine is converted into electricity through a generator.[107] Thermal energy in the exhaust gas can also be recovered for heat or secondary power generators.[108] Heat recovery maximizes the efficiency of these systems.[109]

Microturbines are smaller versions of gas turbines and can range from 30kW to 250kW.[110] Because of their scalability and flexibility in connection methods, microturbines are particularly well-suited for distributed generation.[111] Like gas turbines, heat can also be recovered for productive use. Both gas turbines and microturbines are sensitive to the quality of its fuel source; digester gas contains a variety of contaminants including siloxanes and hydrogen sulfides that can corrode the turbines, which must be removed from the gas before use.[112]

Steam turbines convert energy from high temperature and high pressure steam; steam produced by a boiler drives a generator that produces electricity. [113] With steam (and its boiler) as the intermediary between the fuel source and electricity generation, steam turbines have added flexibility in terms of the fuel types that can be accepted.[114] Thus, when used with digester gas, less conditioning of the gas is necessary to prepare it for use by the steam turbine system. Steam turbines have a wide range of sizes, from 50kW to 250MW.[115]

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106 "Basic Information." U. S. Environmental Protection Agency, Combined Heat and Power Partnership. Accessed June 6, 2010 from http://www.epa.gov/chp/basic/index.html.

107 "Technology Characterization: Gas Turbines." Energy and Environmental Analysis. December 2008.

108 "Technology Characterization: Gas Turbines." Energy and Environmental Analysis. December 2008.

109 "Technology Characterization: Gas Turbines." Energy and Environmental Analysis. December 2008.

110 "Technology Characterization: Microturbines." Energy and Environmental Analysis. December 2008.

111 "Technology Characterization: Microturbines." Energy and Environmental Analysis. December 2008.

112 Personal communication with Joan Fontaine of SEA Consultants by Shutsu Wong on June 15, 2010.

113 "Biomass Combined Heat and Power Catalog of Technologies." U.S. Environmental Protection Agency, Combined Heat and Power Partnership. September 2007.

114 "Biomass Combined Heat and Power Catalog of Technologies." U.S. Environmental Protection Agency, Combined Heat and Power Partnership. September 2007.

115 "Biomass Combined Heat and Power Catalog of Technologies." U.S. Environmental Protection Agency, Combined Heat and Power Partnership. September 2007.

Reciprocating internal combustion engines are the most common small-scale stationary power generation system, found in many applications such as automobiles, trucks and trains.[116] These systems contain a piston and cylinder where four strokes (intake, compression, power, exhaust) complete the power cycle, and through the ignition of the fuel during the compression stroke, the power stroke drives energy generation as the compressed air and fuel are expanded during combustion.[117] The size of reciprocating engines ranges from 10kW to 5MW.[118] The WWTP in Fairhaven, MA will be installing an internal combustion engine for the CHP system; the plant elected to use this engine over newer technologies like microturbines because of its longer history and track record.[119]

Fuel cells are a relatively new CHP technology that has high efficiencies and low emissions,[120] but is still undergoing further development.[121] Their size can range anywhere from 50 watts to 2MW depending on the application.[122] Concerns over high costs and durability currently limit their use.[123] Furthermore, for application at a WWTP, very high levels of fuel conditioning are necessary to adequately prepare the digester gas for use by this sensitive system.[124] The New York Power Authority was the first to successfully use a fuel cell with AD gas in 1997 using UTC Power's PureCell Model 200 at the Yonkers Wastewater Treatment Plant.[125] Since then, UTC Power has discontinued their 200 kW fuel cell and no longer provides any fuel cells for use with digester gas. Future market studies are necessary before UTC Power will consider further development of fuel cells for use with biogas.[126] Despite several successful

[116] "Technology Characterization: Reciprocating Engines." Energy and Environmental Analysis. December 2008.

[117] "Technology Characterization: Reciprocating Engines." Energy and Environmental Analysis. December 2008.

[118] "Technology Characterization: Reciprocating Engines." Energy and Environmental Analysis. December 2008.

[119] Personal Communication with Bill Fitzgerald from Fairhaven WWTP by Shutsu Wong. July 2, 2010.

[120] "Biomass Combined Heat and Power Catalog of Technologies." U.S. Environmental Protection Agency, Combined Heat and Power Partnership. September 2007.

[121] Personal communication with Joan Fontaine at SEA Consultants by Shutsu Wong. June 15, 2010.

[122] "Biomass Combined Heat and Power Catalog of Technologies." U.S. Environmental Protection Agency, Combined Heat and Power Partnership. September 2007.

[123] "Biomass Combined Heat and Power Catalog of Technologies." U.S. Environmental Protection Agency, Combined Heat and Power Partnership. September 2007.

[124] Personal communication with Joan Fontaine at SEA Consultants by Shutsu Wong. June 15, 2010.

[125] "Creating Clean Power with Free Fuel from Anaerobic Digester Gas with the PureCell Model 200 Fuel Cell Powerplant." UTC Power. January 24, 2007. <http://www.utcfuelcells.org/fs/com/Attachments/project_profiles/PP0107_NYPA2.pdf>.

[126] Personal communication with George Brandt of UTC Power by Shutsu Wong on June 21, 2010.

applications in the United States, additional work and studies will be necessary before these systems will be widely used for CHP in conjunction with digester gas.

Lastly *Stirling engines*, which are effectively reciprocating engines that operate on the temperature differentials on either end of a piston, are driven, by external combustion.[127] Because operation is dependent on the temperature differences, cooling must also occur to maintain this system.[128] Stirling engines are well-suited for biogas because they are driven by external combustion; this characteristic allows more flexibility in the fuel quality and cleanliness. This technology is still under development and being considered for residential applications.[129] Relatively small, Stirling engine systems are smaller than 200kW.[130]

Technological Advances in CHP

CHP technologies are constantly evolving as demand for renewable energy sources increases. Within the realm of CHP, the two most prominent advances are the development of microturbines and the introduction of fuel cells. In addition, the use of Stirling engines is also an emerging area.

Microturbines are still considered relatively new in CHP applications, and particularly, for use with digester gas. These turbines can be as small as 30kW and consequently open the application of CHP to wastewater treatment plants that are smaller than many plants that currently employ CHP. For example, Essex Junction in Vermont has successfully installed and used two 30kW microturbines for their 2.0MGD flow, a plant size that was previously considered too small for productive use of digester gas.[131] Furthermore, there is an element of scalability, where the number of turbines can be adjusted to suit the volume of wastewater passing through a plant as needed. Again, in Essex Junction, the plant is now exploring the addition of another turbine since its power generation capacity has been reached.[132]

Fuel cells continue to undergo development, as the technology is still relatively new and has not been tested long term. As discussed earlier, the New York Power Authority installed eight fuel cells from UTC

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[127] "Biomass Combined Heat and Power Catalog of Technologies." U.S. Environmental Protection Agency, Combined Heat and Power Partnership. September 2007.

[128] "Biomass Combined Heat and Power Catalog of Technologies." U.S. Environmental Protection Agency, Combined Heat and Power Partnership. September 2007.

[129] Roth, Kurt, Targoff, J., Brodrick, J. "Using Stirling Engines for Residential CHP." American Society of Heating, Refridgerating and Air-Conditioning Engineers, Inc. Journal. November 2008.

[130] Biomass Combined Heat and Power Catalog of Technologies." U.S. Environmental Protection Agency, Combined Heat and Power Partnership. September 2007.

[131] Eaton, Gillian, Jutras, James L. "Turning Methane into Money: Cost-Effective Methane Co-Generation Using Microturbines at a Small Wastewater Plant."

[132] Personal communication with Joan Fontaine of SEA Consultants by Shutsu Wong. June 15, 2010.

Power that operate on digester gas; since then, UTC has discontinued these fuel cells, demonstrating the need for further development and market assessment. With the first successful installation of a fuel cell in 1997, the long term study of their performance is just beginning to emerge. In addition, due to high costs at the moment, fuel cells are primarily adopted when significant grants are available to make these projects financially feasible.[133]

In addition to the fuel cell driven by digester gas, other fuel cell applications are possible for electricity generation. For example, IntAct Labs of Cambridge, MA is in the process of developing a microbial fuel cell where the *cell* generates electricity directly from waste sludge without the intermediary of digester gas. While still under development, such technologies may offer an alternative for plants that may not have the capital or physical space to devote to full-scale digesters and CHP systems. Essentially, this type of microbial fuel cell permits the WWTP to skip a step. But, the practical application of such a system and its costs, particularly for use at municipal wastewater treatment plants has yet to be developed and tested.

Lastly, as discussed earlier, Stirling engines are a relatively new CHP type that is still undergoing testing and has not been applied for wastewater treatment. Most notably, Stirling engines provide three advantages: reduced noise and vibrations, flexibility in fuel sources due to an external combustion system and lower emissions. At the moment, the technology is not yet competitive despite its advantages.

CHP systems can be a single technology or a combination of technologies, allowing them to take advantage of a combination of system characteristics. For example, in Portland, Oregon, the Columbia Boulevard Wastewater Treatment plant successfully installed a 200kW fuel cell in 1998, and in 2003, installed four 30kW microturbines for additional power generation using surplus digester gas.[134] Another 1,500kW capacity is being considered for the remaining excess gas.[135]

[133] Personal communication with Christine Brinker of Intermountain CHP Application Center by Shutsu Wong. June 22, 2010.

[134] "Columbia Boulevard Wastewater Treatment Plant: 320kW Fuel Cell and Microturbine Power Plants." CHP Case Studies in the Pacific Northwest, U. S. Department of Energy Energy Efficiency and Renewable Energy.

[135] "Columbia Boulevard Wastewater Treatment Plant: 320kW Fuel Cell and Microturbine Power Plants." CHP Case Studies in the Pacific Northwest, U. S. Department of Energy Energy Efficiency and Renewable Energy.