REACHING ZERO-NET ENERGY AT WATER AND WASTEWATER TREATMENT FACILITIES

An Interactive Qualifying Project Report,

completed in partial fulfillment of the requirements for

the degree of Bachelor of Science at

Worcester Polytechnic Institute

By

Calvin Nguyen

Kai Tang

Yechan Won

Submission Date: March 7, 2014

Abstract

Due to the high energy consumption at water and wastewater treatment facilities, it is crucial to reduce energy consumption and possibly achieve energy independence at these facilities. This project was completed to develop a methodology to achieve energy independence at three selected water and wastewater treatment facilities located in Pepperell, Southbridge, and Millis in Massachusetts. The methodology included site screening, energy audit analysis, renewable energy assessment, and economic analysis. Results showed that Southbridge could reduce energy costs, and facilities in Pepperell and Millis could achieve zero-net energy demand. The approach serves as a template that can be applied for analysis of other water and wastewater facilities.

This report represents the work of one or more WPI undergraduate students submitted to the faculty as evidence of completion of a degree requirement. WPI routinely publishes these reports on its website without editorial or peer review

Acknowledgements

Authorship Page

IQP Report
Written by: All

Millis Report
Written by: Calvin Nguyen

Pepperell Report
Written by: Yechan Won

Southbridge Report
Written by: Kai Tang

Table of Contents

List of Tables

List of Figures

1.0 – Introduction

Each year, approximately 370 public water and wastewater treatment facilities (municipal and districts) in Massachusetts process and distribute approximately 662 billion gallons of water to the local community (Cynthia, 2010). Due to the large amount of energy required by water and wastewater treatment facilities, water and wastewater treatment facilities use, on average, 30 to 40 percent of the total energy consumed in Massachusetts and are considered one of the largest energy consumers in their community. Moreover, with advanced treatment requirements, their energy consumption is expected to increase by 20 percent within 15 years (EPA, 2009). Therefore, reducing energy consumption of the water and wastewater treatments will increase the amount of energy available for other commercial and industrial uses and promote a more robust economy.

The Commonwealth of Massachusetts has established a number of initiatives to promote effective energy management. The Energy Pilot and Energy Leaders Initiative at drinking water and wastewater treatment facilities was developed in 2007 in collaboration with the Massachusetts Department of Energy Resources (MassDOER), U.S. Environmental Protection Agency (EPA), University of Massachusetts - Amherst, Massachusetts Renewable Energy Trust, Consortium for Energy Efficiency, and a number of major gas and electric utility companies in Massachusetts. MassDEP has set aggressive energy and pollution reduction goals with a target goal to achieve zero-net energy at 74 drinking water and wastewater facilities, approximately 20 percent of the total municipal facilities in Massachusetts, by 2020. In November 2011, the Patrick-Murray Administration launched the Clean Energy Results Program (CERP), a unique partnership between MassDEP, MassDOER, and the Massachusetts Clean Energy Center

(MassCEC) (Jorgenson, 2011). This program will further encourage the expansion and development of energy efficiency and clean energy projects in the water sector. These initiatives provide a strong foundation for encouraging clean energy in the water sector. To further advance these initiatives and promote energy efficiency, more detailed case studies are necessary.

The goal of this Interactive Qualifying Project (IQP) is to develop energy improvement plans to reach zero-net energy for three selected treatment facilities, and provide guidelines for the application of these plans at other facilities. To accomplish this goal, it is necessary to assess the current technological improvements and renewable energy methods available for achieving zero-net energy, identify the economic costs and benefits of adapting these new technologies, and analyze any environmental issues associated with installing and maintaining the technologies. Once the upgrades are identified and analyzed, the energy improvement options will be selected according to the facilities' current performances and available resources. The economic and environmental aspects as well as the feasibility of the energy improvement plans will be summarized in a report and reviewed by the facilities operators before project execution.

This IQP report is divided into four chapters: the introduction, literature review, methodology, result, and conclusion. The literature review addresses the results of past zero-net energy projects, available energy improvement options, environmental aspects of the project as well as financial assistance. The methodology presents the procedures involved in developing zero-net energy plans for the facilities addressed in this project. This chapter also describes the approaches the team will use to research, benchmark, and provide recommendations for each selected facility. The result presents the findings from site screenings and renewable energy feasibility studies at the site. The conclusion provides the most recommended upgrades and

implementations in order to reach the zero-net energy at the sites based on economic and

environmental analysis.

2.0 – Literature Review

The goal of this section is to provide background information on previous work done related to the ZNE project, what treatment facilities require, and available financial assistance. This section will also provide background information on the available energy efficient technologies and renewable energies and each of their impact on energy consumption and the environment.

2.1 – The Growing Energy Crisis in the 21st Century

The world energy consumption grows continuously every year and about 27 percent of the world's energy is lost in energy generation and transmission. In 2012, the world consumed approximately 145,475 TWh of energy, which is 1.4 percent higher than the previous year's energy consumption (World Energy Statistics, 2012). In addition, the International Energy Outlook 2013 projected that the world energy consumption will increase from 143,851 TWh to 224,407 TWh within 30 years (EIA, 2013). The annual energy consumption growth is heavily affected by the countries outside of the Organization for Economic Cooperation and Development (OECD), where energy demand is continuously increasing due to long-term economic growths. In fact, energy consumption increased by 90 percent in the non-OECD countries while that of the OECD countries increased by only 17 percent (CNBC, 2013). As one of the non-OECD countries, China recently became the world's biggest oil importer as a result of fast economic growth and strong auto sales. In contrast, the United States decreased its dependency on oil and its crude oil production exceeded the imports in October 2013 for the first time since 1995 (Oil Patch Asia, 2013). Because of the increasing demand and cost for energy from fossil fuels around the globe, becoming energy independent will be an important goal for

the ZNE project. Not only is energy becoming a crisis but also the amount of greenhouse gas being generated is affecting the long-term environmental and economic health of the world.

2.2 – Impacts of the Fossil Fuel-Based Power Generation on the Environment

The amount of electricity generated is closely related to the greenhouse gas (GHG) emission because currently, most of the electricity generated comes from fossil fuel. The GHG emission affects the climate and accelerates the global warming by trapping heat within the atmosphere on Earth. Global warming is a serious environmental issue since it changes the climate throughout the world and increases the sea level as ice melts at the Polar Regions. Also, burning fossil fuels contributes to other types of pollution including smog, haze, acid rain, and ocean acidification. Fossil fuel-based electricity generation is a dominant source of the GHG emission throughout the world where over 60 percent of the total electricity comes from the fossil fuel-based electricity generation. This amount alone accounts for nearly 33 percent of the air emissions in the world (CO_2 Now Org, 2013). Moreover, it is also responsible for 67 percent of the world's sulfur dioxide emissions, 40 percent of carbon dioxide emissions, and 23 percent of nitrogen oxide emissions (EPA, 2013). The amount of air emission continues to increase as more energy is consumed every year; the study, the Journal Earth System Science Data Discussion, found that the world is set to emit nearly 36 billion metric tons of CO_2 by the end of 2013. The projected value is about 2.1 percent higher than the previous year's gas emissions and 61 percent higher than that of 1990 (Ghose, 2013). Increase in GHG emissions is primarily due to the non-OECD nations' rapid industrialization. In fact, the non-OECD nations had positive percent changes in air emissions while most of the OECD nations had negative changes. China, the world's largest carbon emitter since 2006, accounted for 70 percent of the global GHG emission growth in 2012, releasing over 7.7 billion tons with an annual emission increment of

5

7.9 percent (Business Recorder, 2013). Figure 1 represents the global CO2 emission from fossil fuel combustion and some industrial processes for each major country involved in 2012 (Saga Commodities, 2013).
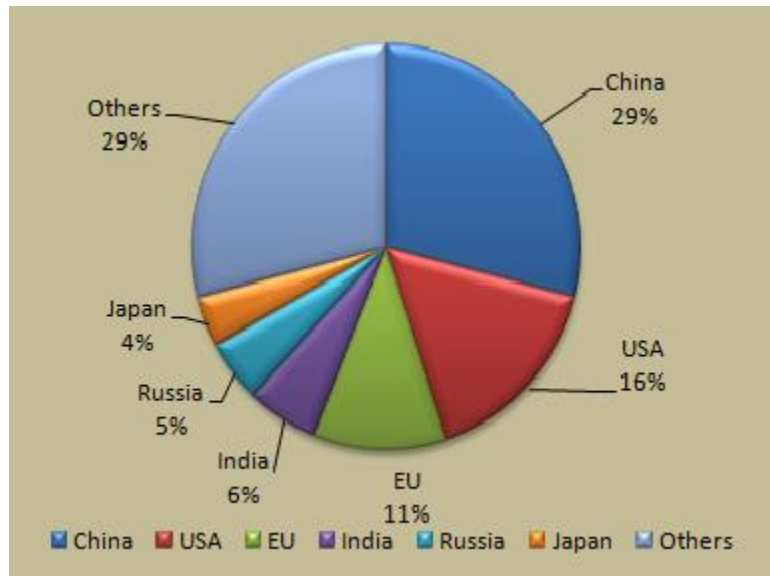
Figure 1. The Global CO2 Emission (Saga Commodities, 2013)

Knowing the environmental effects of clean energy generation before installing the generators is critical. Air emission associated with solar, wind and hydropower is negligible because no fuel is being burned. Although these technologies are clean and eco-friendly, they do have the potential of harming the environment to some extent. Hydropower facilities create no pollution during electricity generation, however, construction and operation may cause an impact on river ecosystems and surroundings. Solar panels create CO_2 and other toxic wastes during the manufacturing process. CHP has a high-energy efficiency when burning biogas, but does emit greenhouse gas emissions during the combustion process.

Nevertheless, renewable energy generators create significantly low amounts of air emissions and other pollutants compared to fossil fuel-based power plants in the long term. Moreover, renewable energy generators make use of the resources that are readily available

everywhere and are continuously replenished by resources such as sunlight, wind and water. Figure 2 shown on the next page provides CO_2 emission comparisons between fuel-based energy and renewable energy generations (Armannsson, 2006). (**Note**: Karahnjukar and Krafla are two power stations located in Iceland.)
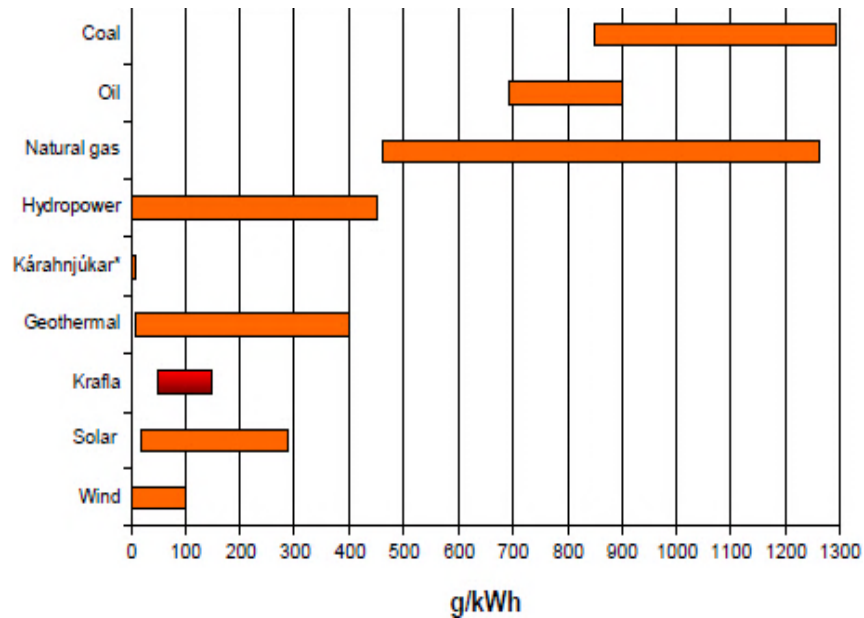
Figure 2. CO2 Emissions from Electricity Generation (Armannsson, 2006)

Without a doubt, implementing renewable energy generators will result in energy independence, economic benefits, and a cleaner environment.

2.3 – Energy Consumption and Air Emissions Abatement Plans

In order to reduce the air emissions and energy consumption, the world has developed environmentally friendly plans and adapted energy efficient and clean technologies. Some countries employ carbon taxes to motivate energy users to reduce their consumption. One form of the carbon taxes is a tiered energy tax where the energy consumers have baseline energy allowances that carry a low tax. If the energy usage exceeds the baseline, the tax increases dramatically. The US currently doesn't impose carbon tax although some states employ the

tiered energy tax which offers much greater renewable energy benefits for high energy consumers to get them to change.

Another way to conserve energy is promoting energy efficient buildings. Net zero energy buildings (NZEB) are currently an emerging performance target for sustainable commercial buildings, for they require least amount of energy, which can be covered by the renewable energy technologies. This is very crucial to reducing the GHG. Without energy efficiency and fossil fuel abatement in buildings, the national targets for GHG emissions reductions cannot be achieved. In effect, commercial and residential buildings consume almost 70 percent of the electricity in the US (EIA 2005). Electricity consumed in the commercial and industrial buildings doubled between 1980 and 2000 and is expected to increase more every year (EIA 2005).

The National Renewable Energy Laboratory (NREL) classified the NZEB into four categories which are the Net-Zero Site Energy, Net-Zero Source Energy, Net-Zero Energy Cost, and Net-Zero Emissions buildings (Pless, 2010). The Net-Zero Site Energy produces enough renewable energy to power the building throughout the year. The Net-Zero Source Energy produce and purchase enough renewable energy to cover their annual energy use. The Net-Zero Energy Cost generates and sell enough renewable energy to the power plants to cover the cost of energy purchased from the power plants. Finally, the Net-Zero Emissions buildings produce or purchase enough renewable energy to counterbalance emissions from the buildings' annual energy use. Most of the small buildings that require less energy for operation and maintenance can easily achieve energy independence through renewable energy options. However, heavily occupied buildings that require high maintenance and operation cost such as hospitals and groceries may require energy outsourcing, becoming either the source NZEB or the Net-Zero Emissions buildings.

The NZEBs minimize the energy loss by adapting energy efficient building designs and reducing transportation, transmission, and conversion losses. Also, the NZEB require renewable energy sources that are widely available over the lifetime of the building. The NZEB make use of supply-side and demand-side renewable energies to become energy independent. The supply-side renewable energies come from the energy generation technologies such as solar panels, biofuels, wind turbine, and hydropower turbine. The demand-side renewable energies include passive solar heating, solar ventilation air preheaters, and domestic solar water heaters (Pless, 2010). In order to achieve the maximum performance of the NZEB, it is necessary to consider the energy efficiency of the building first and then the energy generating options. Moreover, the footprint space availability and the renewable sources at the site must be checked before making any modifications and installing new technologies.

Although it is important, energy efficiency alone cannot achieve the energy independence of the building. In fact, the renewable energy generation technologies have to be implemented to reach the energy independence. Every year, the amount of energy produced from the renewable sources increases in attempt to reduce GHG emissions and gain energy security. In 2012, the world has invested $344 billion for the renewable energy, which is 12 percent less than the previous year's investment due to economic depressions (FS UNEP center, 2013). In addition, the OECD countries' investment for the renewable energy was just 18 percent higher than that of the developing non-OECD countries. This is a dramatic change since 2007 when the OECD countries invested almost three times more than the non-OECD countries. Additional solar photovoltaic installation increased the total power capacity of 30.5 gigawatts and the wind reached up to 48.4 gigawatts of the capacity. The total renewable power capacity worldwide reached 1,470 gigawatts (Worldwatch Institute, 2013). China was the dominant country in

implementing renewable energies among the non-OECD countries, investing $67 billion (Morales, 2013). Likewise, the Middle East and Africa doubled their investment to $12 billion. On the other hand, the US and German lowered their investments for the renewable energy to $36 billion and $20 billion, respectively. The only country out of the OECD nations that increased the renewable energy investment was Japan whose budget surged 73 percent to $16 billion to support wind, solar and geothermal power generation after the earthquake in 2011 (Worldwatch Institute, 2013). The US generates 14.2 percent of the nation's net electricity from the renewable sources that is less than the world's average of 16 percent (Bossong, 2013).

2.4 – Creating an Energy Management Partnership Model

In 2007, in an attempt to reduce the facilities' energy consumption and greenhouse gas emissions, the Massachusetts government developed the Massachusetts Drinking Water & Wastewater Facilities Energy Management Pilot Program. The overall goal of this program was to reduce energy costs and greenhouse gas emissions by 20 percent and create a new public and private partnership model. Led by MassDEP, the energy pilot brought together the state and federal agencies, electric and gas utilities, and other partners to assist 14 participating water and wastewater treatment facilities across the state. This pilot project conducted energy audits and evaluated the potential of producing on site renewable energy for each facility. By adapting to energy efficient technologies such as variable speed drives (VSDs) and treatment process improvements, and on-site renewable power generation (i.e. solar photovoltaic system, wind turbines, in-line hydropower, and combined heat & power (CHP)), over $3.7 million of annual energy savings were identified.

In 2009, as a result of leadership by Governor Patrick's Administration and EPA, the Massachusetts Energy Pilot became a national model that led to the creation of a new national

"20 percent green infrastructure" requirement for State Revolving Fund (SRF) assistance under the American Recovery and Reinvestment Act (ARRA). As a result of the new ARRA funding, seven more plants in Massachusetts were added to the project and a total of $66.1 million was provided to implement all energy-saving opportunities at the 21 facilities overall. In total, this energy initiative has resulted in over $5 million of annual energy savings for taxpayers, has reduced energy costs and greenhouse gas emissions by over 34 percent, and was responsible for having installed power generators generating a total of over 10 megawatts of clean renewable power for the facilities. More specific data on this past ZNE project can be found in the appendix section.

2.5 – Energy Requirement for Water and Wastewater Treatment Facilities

Nationally, a significant amount of the municipal energy use occurs at water and wastewater treatment facilities. With pumps, motors, and other equipment operating all year round, the water and wastewater treatment facility consumes up to 75 billion kilowatt-hours of energy and produce 45 million tons of greenhouse gas into the atmosphere (EPA, 2009). As shown in Figure 3, energy accounts for 27 percent of the operating cost for a typical water or wastewater treatment facility in the USA.
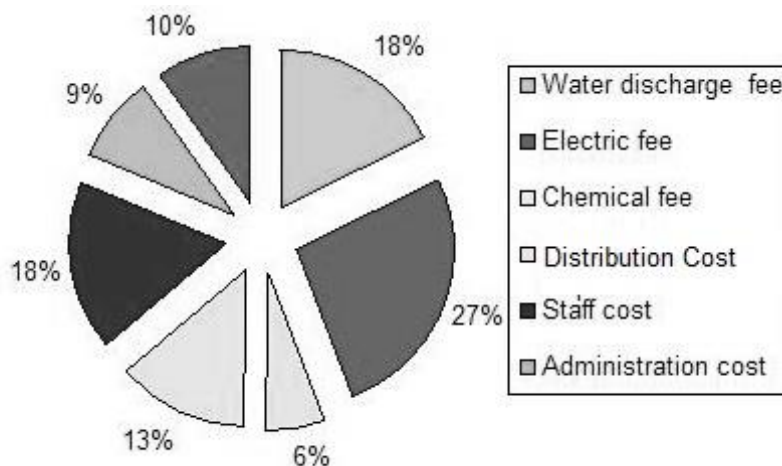
Figure 3. Industry Average Operation and Maintenance Budgets (EPA, 2009)

Water and wastewater management systems both rely on a network of pump stations, transmission lines and storage components to transport flow to various unit operations and treatment processes. However, as shown in Figure 4 below, energy costs are different for water and wastewater treatment processes (Cynthia, 2010).
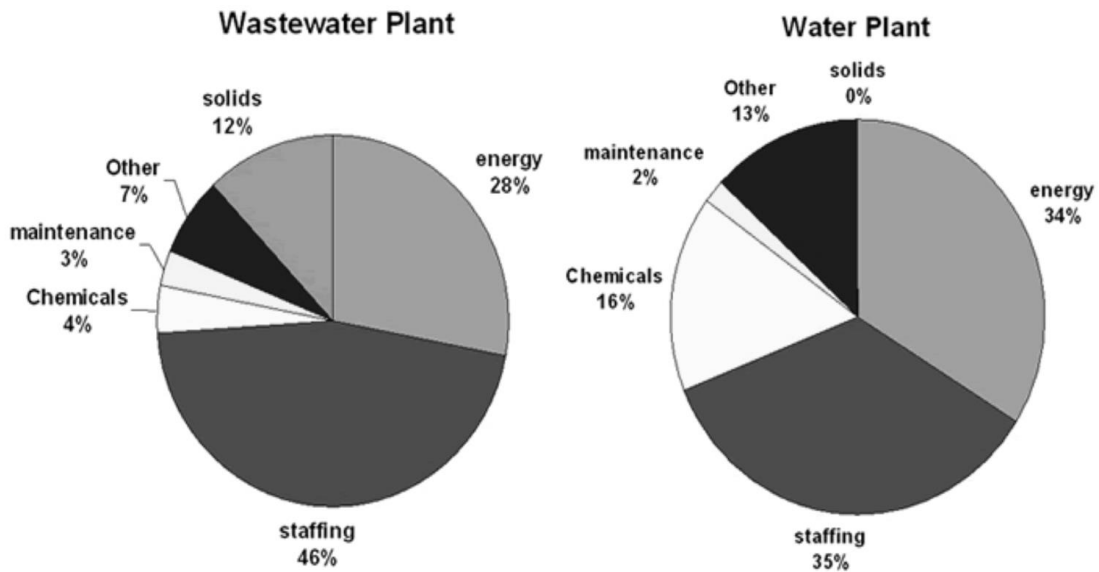
Figure 4. Energy Profiles of a Typical Water and Wastewater Treatment Facility (Cynthia, 2010)

Water treatment facilities have pump stations that transport raw water to the treatment and distribution systems. Raw drinking water treatment options often vary from plant to plant but can include coagulation, flocculation, sedimentation, filtration, and disinfection processes. A typical profile of total electricity use in a water treatment facility is 86 percent for distribution pumping, 8 percent for raw water pumping, and 6 percent for treatment process as shown in Figure 5. About 80 to 90 percent of energy consumption for drinking water treatment facilities is associated with pumping raw water and distributing processed water (Greenberg, 2011).
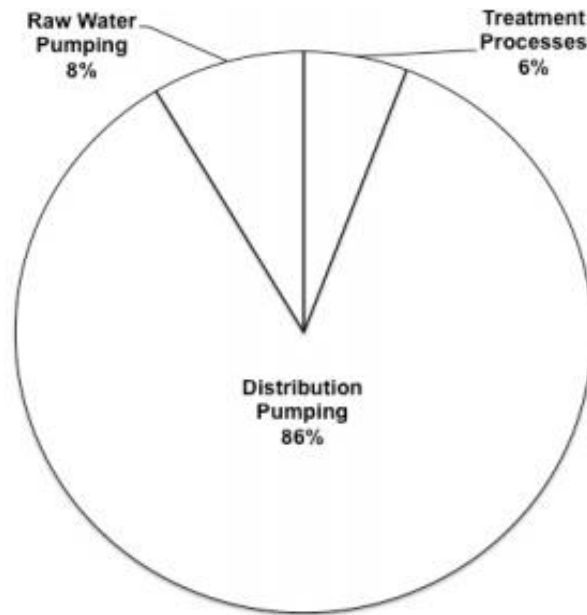
Figure 5. Drinking Water Treatment Facility Energy Profiles (Greenberg, 2011)

Wastewater treatment facilities have pump stations for collecting and delivering wastewater to a treatment system. Most of the wastewater treatment facilities have preliminary, primary, and secondary treatment processes in which wastewater is pumped and further purified in each process. Tertiary or advanced treatment is now becoming more common to meet higher water quality standards by the EPA. For wastewater treatment facilities, aeration and sludge treatment process accounts for most of the energy consumption. In addition, UV disinfection, which is becoming more common for treating wastewater, uses a large amount of energy as well. The typical energy profile of a wastewater facility is 56 percent for aeration, 10 percent for pumping, 9 percent for lighting, and the rest for treatment process as shown in Figure 6 (Greenberg, 2011).
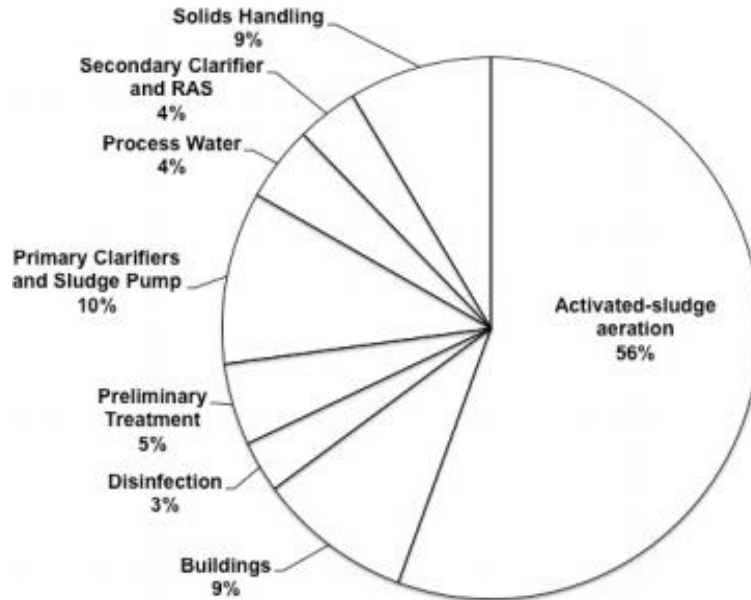
Figure 6. Another Energy Profile of a Typical Wastewater Treatment Facility (Greenberg, 2011)

In all cases, the energy use for the treatment process is much greater than the energy used for maintaining the buildings, as shown in Figure 5 and 6. From this information, optimizing the pumping and aeration system for the water treatment process will greatly reduce energy consumption in those areas for water and wastewater treatment facility.

2.6 – Renewable Energy Technologies

On-site energy generation is crucial for energy independence. Renewable energy technologies promote energy security and lower air emissions since they use clean and widely available natural resources. The most commonly used renewable energy technologies include wind turbines, solar panels, co-generation systems using biogas, and hydropower generators. Once installed, these renewable energy technologies generate electricity with significantly lower operational and maintenance costs that is more environmentally sustainable than fossil-fuel generated energy.

2.6.1 – Wind Power

Introduced in the late 1800s, wind power is a clean renewable energy source that requires a turbine to convert mechanical energy from the wind to electricity. Today, there are two major types of wind turbines: horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWT). HAWTs are more efficient when compared to VAWTs and can produce 70 to 85 percent electricity of its lifetime, but can only deal with the wind facing the rotor and are weak in turbulent conditions. VAWTs are smaller sized wind turbines that are suitable for residential use and can receive wind blowing from any direction.

The efficiency of wind power is determined by a capacity factor. The capacity factor describes the ratio between the potential and actual energy output of the generator. On average, the capacity factor of a wind turbine is approximately 30 percent (EEA, 2013). During the turbine's lifespan, it is estimated that it will work for approximately 120,000 hours. The lifespan of wind turbines is approximately 20 years to as long as 30 years (EWEA, 2013). By then, the wind turbine would be very inefficient to operate and would need to be replaced.

The advantage of having a wind turbine is that the maintenance cost becomes cheaper as time progresses. A study done in Denmark demonstrated that new generations of wind turbines when compared to older generation of wind turbines have a lower maintenance cost. For old wind turbines, the maintenance cost for each turbine is, on average, 3 percent of the original cost of the turbine each year. For the newer wind turbines, the annual maintenance cost is between 1.5 percent and 2 percent of the original

15

investment (WMI, 2013). The cost of installing the wind turbine is $1.3-2.2 million per MW (Bluhm, 2012).

There are a few disadvantages associated with the use of wind turbines. One disadvantage is the limitation of having to place a wind turbine at an ideal location where enough wind would pass through. The wind turbines also need to be designed to reach above 30 m above the ground to take advantage of fast and less turbulent wind. Also, it requires minimum of 10 mph of wind speed to spin the blade. To maximize the efficiency of the wind turbine, a wind speed above 14.5 mph is preferred. Wind turbines can handle at most 35 mph of wind speed but once the wind speed approaches 50 mph, the wind turbines shutdown for safety and to prevent damage so at certain times of the year, the wind turbine will not be running (European Wind Energy Association, 2013). Location is very important in determining whether to implement wind turbines or not. The other disadvantage is that the blades wear out as time passes due to wind corrosion; however, this issue can be negated by adding rubber tips to the blades. Wind turbines also are much less efficient during the winter. Additionally, potential noise from a wind turbine impacts should be an important consideration when planning a land-based wind turbine project. In the summer of 2013, MassDEP has setup a Technical Advisory Group to advise the agency on issues related to Wind Turbine Noise. The Wind Noise Technical Advisory Group (WNTAG) has been established as part of EEA Secretary Sullivan's recently announced inter-agency initiative for state energy and environmental agencies to provide support and guidance to municipalities, developers, and stakeholders for land-based wind projects. Lastly, the lifespan of the wind turbines is very low compared to other types of renewable energy power plants that may mean costs will be even higher even though the

maintenance fee is low. This disadvantage also means that the payback for using wind turbines is long meaning that by the time that the payback time is finished, the wind turbine has met the age of its lifespan. However, wind turbines take up a large area since the wind turbine site has to be accessible by a crane. Also, it needs to be built at least 9 m above any structure within 90 m of the site to get an uninterruptable wind source.

Most of the drinking water treatment facilities do not require a large wind turbine that generates over 1 MW of energy because of their relatively low energy consumption. Without a doubt, installing a small wind energy system is a better choice for small to mid-sized water treatment facilities. The small wind energy system is defined as any wind turbine with a maximum output capacity of 100 kW. According to National Renewable Energy Laboratory (NREL), annual energy output can be determined with following equation:

$$\textbf{Output } (\textbf{W} \cdot \textbf{h}) = \textbf{0.01328} \times \textbf{rotor diameter}(\textbf{ft})^2 \times \textbf{wind speed}(\textbf{mph})^2$$

Small wind systems generally cost from $3,000 to $5,000 per kW. This is simply the cost of the main components. If engineering costs and the tower cost are included, the project cost doubles. Wind turbines become more cost-effective as the size of the rotor increases because more electricity can be generated and the building cost does not increase as much. In fact, 10 kW wind turbine costs around $60,000 while 100 kW wind turbine costs around $500,000 although 100 kW turbines generate about seven times more electricity than 10 kW turbines annually. After construction of the wind turbines, the marginal cost of wind energy can be as cheap as $0.01 per kWh. The cost of electricity produced has become much cheaper over the century as newer technologies and materials. Examples would be improvements in the turbine motor performance, increased

17

power production efficiency, lighter and longer turbine blades and so on. Payback can average around 10 years.

In terms of the amount of pollution generated by wind turbines, they do not release any type of pollutant during its operation (note hydraulic oil for lubricating the turbine can be a potential pollution source). In fact, it is one of the cleanliest power generating technologies available today on the market. Replacing the electricity purchased from the gas or coal power plant with electricity produced from wind turbine will result in a net reduction of greenhouse emissions.

2.6.2 – Solar Photovoltaic (PV)

Solar photovoltaic technology converts solar energy directly into electricity. An array of solar panels consisted of numerous solar cells has a capacity of producing 1 kW per 10 m^2. The average cost for solar electricity has fallen by 24.4 percent since last year. Also, the efficiency of the solar electricity has increased by 5.5 percent over the last six years from 17 percent to 21.5 percent, which means that the same-sized panel will generates 60 percent more electricity (Detwiler, 2013). The efficiency of the solar panel is directly proportional to the weather; if the sun is high in the sky on a clear day, it will produce more energy while it will produce less when on a cloudy day.

Solar arrays have a lower capacity factor of 25 percent, which is less than other industrial sources of electricity. Also, every year, the conversion efficiency is reduced by 0.5 percent annually meaning that the solar panels lose their efficiency as they age when generating electricity (Cooler Planet, 2009). Another disadvantage of using photovoltaic solar panels is that depending on the location and the time of the year, solar panels will only be able to capture light for a small amount of time i.e. a few hours. On average, in

the United States, solar panels will only be able to be used to their full potential for 4-5 hours a day on a sunny day (PENetwork, 2013).

The amount of energy generated by the solar system depends on the number of hours of sunshine per day. In general, the average solar hour per day in Massachusetts is about four hours. For every 80 ft^2 that the solar panels occupy, they generate about 1 kW. The total electricity being generated by the PV can be represented by the following equation (SRoeCo, 2013).

$$\textbf{Output } (\textbf{W} \cdot \textbf{h}) = \textbf{365} \times \textbf{solar hours/day} \times \textbf{array size} \times \textbf{derate factor}$$

Currently, solar energy costs around $0.37 per kWh, which is seven times more than the cost for electricity generated by coal, or oil, which is priced at $0.05 per kWh. The average cost of solar electricity decreases each year and with government subsidies, the cost can be reduced as low as the fossil based-fuel energy cost. Solar panels need minimal amount of maintenance since during the 30-year lifespan, the only service needed is replacing the PV batteries and make sure the panels are clean (Strecker, 2013).

Solar panels normally have a 30-40 year life span. The building cost of solar panel is approximately $4,000 per kW (Green, 2012). Due to its high installation cost, it is recommended for the water treatment facilities to partner with a third party company that would provide the power purchase agreements (PPA) and solar leases unless there are low interest rate loans available. For PPA, the installer builds the solar system on a customer's property at no cost and sells the power generated to customers. When they build the solar PV system, private companies can take advantage of the tax credit that the public utilities cannot and receive incentives provided by the government, which can cover up to 50 percent of the project cost. At the end of the contract, the customer can

either extend the contract or buy the whole solar system (SEIA, 2013). For the solar

lease, the customer pays the installer over a period, similar to automobile leasing; the

customer can either pay the bill monthly or pay the lease fee all at once and receive a

discount. Overall, solar power can be beneficial to a facility plant, depending on the

weather and size of the onsite solar power plant.

2.6.3 – Anaerobic Digestion (AD)

Wastewater treatment facilities process millions of gallons of wastewater every

day, which has a great potential to generate energy through anaerobic digestion (AD).

AD process follows the sludge settling and thickening steps where the sludge is

transported to the digester. In the digester, anaerobic bacteria break down biodegradable

organics to produce biogas that contains up to 60 percent methane by volume. Addition

of food waste can increase the productivity of digestion due to high organic

concentrations and volatile solid decomposition rate. In fact, food waste produces about

376 m^3 gas/ton which is approximately three times larger than the biomass which

produces about 120 m^3 gas/ton (Moreno, 2010). There are three different categories for

municipal wastewater anaerobic digesters. They are mesophilic, thermophilic, and

temperature-phased systems. The mesophilic digester, which is common, operates at

temperatures between 20 and 40 degrees Celsius with the average being 37 degrees while

the thermophilic digesters operate between 45 and 75 degrees Celsius with the average

being in the mid-50s. The difference is that the thermophilic digesters produce biogas

faster than mesophilic but at the cost of the energy needed to sustain a warmer

temperature inside the digester. For municipal solid wastes, there are three systems,

which are single-stage wet digesters, dry fermentation, and two-state digesters (ABC, 2013).
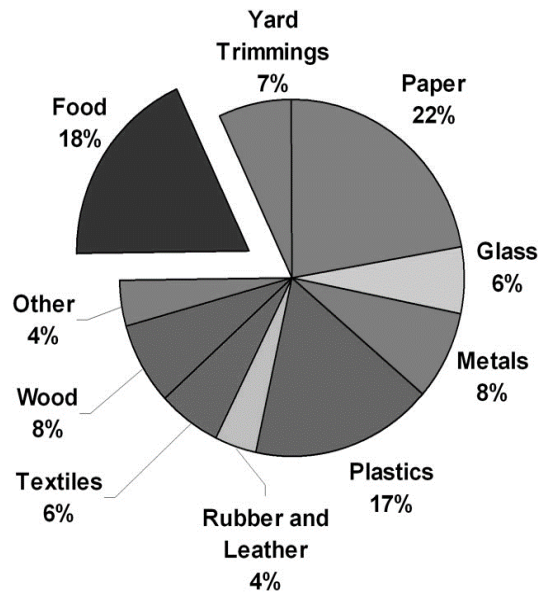
Figure 7. Municipal Solid Waste Sent to Landfill (Moreno, 2010)

As shown in Figure 7, food waste comprises approximately 18 percent of the total municipal solid waste in the US. Over 30 million tons of food waste is produced every year while only about 3 percent of it is used for beneficial purposes such as AD (Moreno, 2010). Food waste not only results in greater energy generation, but also reduces solid disposal volumes in a short amount of time. At the Massachusetts Water Resource Authority (MWRA) treatment facility at Deer Island, total solid wastes generated from wastewater treatment process are reduced by 55 percent after adapting AD (Wong, 2011). Hence, making use of food waste decreases the amount of waste that must be transported off-site for landfill, reducing the waste transportation and increasing revenue for tipping fees.

To increase the energy efficiency, AD is often installed with a combined heat and power system (CHP). Combining CHP and AD is economic as it burns the biogas that is produced on site from the waste to generate power and heat for the facility. The principal technical advantage of CHP is its ability to recover and utilize energy produced from burning the fuel. In fact, CHP has an overall efficiency of 85 percent compared to an overall efficiency of 58 percent for conventional generators that produce electricity and heat separately (UNEP, 2003). Also, using CHP reduces or possibly eliminates dependency on the electric grid, saving electric costs and achieving energy security. Implementing CHP at the facility is highly recommended when the electricity price is high and the fuel price is low. However, due to its high project cost, it is not viable to install CHP in a facility that operates with an average electricity load less than 1 MW. Larger engines usually require permits prior to project commencement.

There are many types of CHP technology including reciprocating engines, combustion gas turbines, micro-turbines, steam turbines, and fuel cells. A reciprocating engine is a heat engine that uses multiple reciprocating pistons to compress and ignite the gas and air mixture to generate energy. About 30 percent of the energy it generates converts into electricity, 50 percent to thermal energy, and the rest are lost via exhaust and radiation. The reciprocating engines are available with many different sizes ranging from 5 kW to 10 MW. An average project cost of a reciprocating engine is $1,800 per kW of capacity (ADIAC, 2009).

A combustion gas turbine is a type on internal combustion engine, which generates high temperature and high-pressure gas into a turbine, converting the shaft

work into electricity. A multiple staged combustion gas turbine system is favored due to its high electric efficiency. The combustion turbines are available from 1 MW to couple hundred MW capacity with relatively low installation cost per kW. For a 5 MW gas turbine, the total installation cost is around $1,200 per kW it generates (DNREC, 2010).

A microturbine is very small combustion turbine with output ranging from 30 to 400 kW of capacity. Microturbines consist of a compressor, combustor, turbine, and generator. These microturbines are designed to generate power for commercial buildings and light industrial applications. Moreover, they are designed for continuous-duty operation and are recuperated to achieve higher efficiencies (around 30 percent electric efficiency). Because it is somewhat still a new technology, it is more expensive than other CHP technologies. For a 65 kW unit, the total project cost is about $2,500 per kW (Devlin, 2010).

A steam turbine is one of the oldest types of power generating technologies, which is designed to generate thermal energy unlike the reciprocating and gas turbines. Due to their versatility and ability to operate with many different types of fuels, steam turbines are widely used for CHP applications. During the process of heat generation, high-pressure steam rotates the turbine, converting mechanical energy into electricity. The capacity of steam turbines can range from 50 kW to several hundred MW (Develin, 2010).

Fuel cell is an alternative energy source that generates electricity through electrochemical processes rather than combustion. There are many types of fuel cell technology, but the mostly used ones are the alkaline fuel cell (AFC), proton exchange

membrane (PEM), molten carbonate fuel cell (MCFC), phosphoric acid fuel cell (PAFC), and solid oxide fuel cell (SOFC). Each fuel cell technology has a different reaction temperature, catalysts, and electrolytes. Due to differences in their chemistry and operating conditions, the fuel cell technologies have many different applications (EERE, 2011). The main components of a fuel cell unit consist of an anode, a cathode, and electrolytes. Hydrogen is introduced as fuel to the anode side of the cell stack where hydrogen is separated into electrons and hydrogen ions. Since electrons cannot pass through the electrolyte, they travel through an external circuit where they are converted from a direct current (DC) to an alternative current (AC). In order to reduce greenhouse gas emission, liquid gas is usually treated with a hydrodesulphurization (HDS) process before producing hydrogen through chemical reactions (Al-Megren, 2008). Fuel cell technologies are available with a wide range of capacity from 5kW to couple MW. They are usually very expensive to install and maintain. An average installation cost for a fuel cell is $4,500 per kW of capacity. Although AD and CHP are very energy efficient, there are many challenges present in installing them. Since AD is often a batch system, it requires large tanks to hold biomass for a certain period to produce biogas, which makes a small AD system very ineffective and impractical. Land requirement for AD is usually around half to one acre. Also, installing ADs can very expensive and requires a significant amount of investment. The cost for building AD ranges from $3,000 to 12,000 per kW. Therefore, a 100 kW system will likely cost around $1 to $1.2 million while a 500 kW system will likely cost around $2 to $2.5 million (Devlin, 2010).

Table 1. CHP Size (Cuttica, 2009)

Type	Size
Combustion Gas Turbine	> 4 MW
Steam Turbine	< 5 MW
Micro Turbine	< 200 kW
Fuel Cell	< 250 kW

Combined AD and CHP system have several limitations along with high project costs. While many available CHP technologies exist, not many producers of CHP technologies have expertise in AD. The digester has many contaminants that may decrease the efficiency and even ruin the components of CHP. In addition, installing AD may result in a very serious odor problem that can affect residents nearby the treatment facilities. Hence, a stringent odor control and dewatering process of sludge must be applied.

Overall, the huge advantage of using anaerobic digesters is the payback time. The payback time for constructing anaerobic digesters and utilizing them would be within approximately three years that is very short when compared to other renewable sources of energy but can only be limited to wastewater facilities (EPA, 2007). The gas produced can be converted into a lot of energy, which can be used for the facility and sold or stored for later use if any extra is leftover from the process. This advantage makes anaerobic digesters worth looking into if the budget is enough to cover the initial investments.

2.6.4 – Hydropower

Hydropower has existed since the late 1800s and is still used today to generate electricity today. The process of how hydropower works is that the turbines in hydroelectric systems convert kinetic energy of the flowing water into electricity. In general, there are three kinds of hydroelectric generation methods. The first most common type of hydroelectric system is the conventional facility. A conventional system is usually a large hydropower system using a dam to store water in a reservoir. Conventional hydropower usually needs a large amount of investment and area. For this particular project, small and micro hydropower systems are more suitable choices and that the only difference is the capacity, and do not need a construction of a dam. The building cost will be significantly decreased when no dam is being built. Hydropower is a clean source of energy, as it does not pollute the air unlike other power plants.

There are two classifications of hydropower turbines, which are impulse and reaction turbines. Impulse turbines such as Pelton and cross-flow turbines are often used for sites with high head (300 m) and low water flow rate (0.5-20 m^3/s) since they primarily convert the momentum of falling water to energy. On the other hand, reaction turbines are used for sites with low head and high water flow rate, for example Francis turbine requires and flow rate from 2 to 800 m^3/s, Kaplan turbine needs head up to 40 m, and flow rate up to 1000 m^3/s (Manno, 2013). They generate energy from the combined action of pressure and moving water. Hence, the runner is placed directly in the water stream and fully submerged or encased to contain the water pressure. There are three main types of the reaction turbines, including Kaplan, Francis, and pump as turbine (PAT). Among these three types of turbines, Francis turbines require a decent amount of

head to operate efficiently as water is introduced just above the runner and does impulse action as well (Gaiusobaseki, 2010). A PAT is a reversed pump system where the motor rotates as water flows through the pipe and generate electricity. The small PAT system requires a minimum head of 10 m and flow rate of 10 liters/second (lps). The equations below are used to determine the power output of the hydropower system depending on the efficiency of the turbine as well as the length of the head and the flow rate (EPA, 2013).

$$\textbf{Power (kW)} = \frac{\textbf{Head (ft)} \times \textbf{Flow (cfs)}}{\textbf{11.8}} \times \textbf{efficiency (Impulse)}$$

$$\textbf{Power (kW)} = \frac{\textbf{1}}{\textbf{2}} \textbf{e} \boldsymbol{\rho} \textbf{AV}^{\textbf{3}} \textbf{ (Reaction)}$$

$$\textbf{Power (W)} = \textbf{5} \times \textbf{head (meters)} \times \textbf{flow (lps) (PAT)}$$

$$\textbf{Energy generation (kWh)} = \textbf{Power (kW)} \times \textbf{Capacity Factor (\%)} \times \textbf{time} \left(\frac{\textbf{hours}}{\textbf{year}}\right)$$

The drinking water treatment plant usually has a large head but a lower flow rate, so the impulse turbine is a good option for the drinking water treatment plant. Most wastewater plants do not have a large elevation change to utilize the impulse turbines efficiently. Therefore, reaction turbine is a good choice for generating power with relatively constant water flow rates and small elevation changes of the water treatment facilities.

Although there are some off-the-shelf hydropower turbines that can be matched to certain range of flow rates and head, they are not as efficient as the custom built hydropower turbines. In fact, many hydropower turbines are custom made to match the head and flow rates of the water treatment facility precisely to maximize the output of the turbine. The only downside of custom built hydropower turbines is its high installation

cost, in which 25 percent is the engineering cost (Gaiusobaseki, 2010). Off-the-shelf

hydropower turbines are relatively cheaper than the custom built turbines. The turbines

listed below are the off-the-shelf low-head hydropower turbines suitable for water

treatment facilities (EPA, 2013).

- **LH-1000 -** This hydropower turbine produces a small power output of 1 kW
  when working with 3 m of head and a flow rate of 500 to 1000 gpm. The
  efficiency for this turbine is roughly 60 percent when running at max potential.
  This model can cost up to $3,000.

- **Canyon Hydro-Kaplan Turbine -** These turbines capitalize on the large amount
  of head of the water when it flows downward hence the name canyon.

- **VLH Turbine -** This hydropower turbine, which is made for larger wastewater
  treatment facilities can produce from 100 kW to 500 kW of power when working
  with from anywhere between two to three meters of head and with a flow of a
  quarter of a million gallons to almost one million gallons of water each day. The
  cost of these turbines, however, can be quite expensive as they can run from
  $500,000 to $1,100,000.

The maintenance for the hydropower turbines can be a bit costly compared to

maintaining other power generators using other renewable energy sources; it is usually

$5,000 for every kW. For example, the WWTF in Deer Island, MA has a maintenance fee

of $134,000 to $256,000 a year for the turbine (EPA, 2013).

Implementation of hydropower turbine has minimal impact on the facility's

operations. The only concern of implementing hydropower turbine is its possibility of

interrupting the water flow, which may trigger biological growth in the turbine (Schultz, 2000). For this reason, it is recommended to install the turbine in the treated water section. Hydropower turbine is a clean energy generator that does not emit greenhouse gas during its operation. Hence, replacing the electricity purchased from the gas or coal power plant with electricity produced from hydropower turbine will result in a net reduction of greenhouse emissions.

In an effort to expand the education, assessment, and implementation of In-Conduit Hydropower (inside a pipe or channel) at Massachusetts' drinking water and wastewater treatment systems, MassDEP, with financial assistance from the Massachusetts Clean Energy Center (CEC), has contracted with Alden Research Laboratory, Inc. This project provides drinking water and wastewater utilities with a clearinghouse of hydropower technologies, an assessment of the statewide hydropower potential, and a screening tool to identify hydropower generation potential (Allen, 2013).

2.7 – Energy Efficient Technologies

Energy efficient technologies often implemented in the water and wastewater facilities include heating, ventilation, and air conditioning (HVAC) system, variable speed drives (VSDs), energy efficient lighting system, and high performance aeration system. With advance in technology and science, modern electric devices gained better performances and energy efficiencies. Because our goal is to reduce energy, improving lighting, and HVAC systems are also things to consider. Considering the fact that the water and wastewater treatment facilities use most of their energy in pumping and

aeration, identifying and upgrading the operation system can be a great start to reduce energy consumption.

2.7.1– Heating, Ventilation, Air Conditioning (HVAC) Improvement

Facilities can reduce energy consumption by operating heating, ventilation, and air conditioning equipment more efficiently by upgrading old units with newer high-efficiency systems. Newer air conditioning systems are 11.5 times more efficient compared to older systems meaning that newer systems can reduce up to 30-40 percent energy usage. Air-source heat pumps and water-source pumps are very efficient, with an energy efficiency ratio of 10.5 and 15.2 respectively (California Energy Commission, Nov 2000). On the other hand, energy consumption can also be reduced by implementing new controllers. Timers and electronic time clocks can manage the system operation by reducing the heating or cooling power and even shutting off the system determined by the occupancy in the buildings. Also, electronic thermostats and computerized energy management systems can automatically manage the energy usage in the building based on outside weather conditions and occupancy in the buildings. All of these improvements can result with significant amount of energy savings, but the actual savings will be different from site-to-site, depending on the technologies being adapted (California Energy Commission, Nov 2000).

2.7.2 – Lighting Improvement

Recent advancement in light bulbs, lamps, and control technologies provide many options for saving energy by upgrading lighting systems. The most cost-effective application is to replace the T-12 lamps with T-8 lamps, which will reduce energy usage

by 33 percent and save $12 per fixture per year (Smyth, 2012). On the other hand, high-intensity discharge lamps are also a good choice, since they are more energy efficient and have a longer life span (16,000-24,000 hours) compared to incandescent lamps (2,000-20,000 hours). The controls also play a vital role of saving energy; the occupancy sensors can result in 25 to 50 percent lighting use as compared to manual switching. In general, lighting accounts for 35 to 45 percent of an office building's energy use, the energy consumption will decrease by 30 percent after installing energy efficient lighting systems at the facilities. In addition, the new lighting technology improves the light level, eliminates flicker or reduces glare, resulting in increased production for the employees (California Energy Commission, 2000).

2.7.3 – Variable Speed Drives (VSDs)

Also known as variable-frequency drives, these electronic systems moderate the speed of the motor to adjust the flow/pressure to achieve optimal energy performance. VSDs operate by adjusting the frequency of the power to change the speed of the motor. The purpose of VSDs is to make the pumps delivering water become as energy efficient as possible. VSDs can also be used in wastewater plants to manage the aeration and chemical feed for energy saving. One of the largest energy consumption systems at the water treatment facilities is pumping and aeration and VSDs aim to solve that issue. By using VSDs, energy consumption can be lowered versus using single-speed drives. Another advantage of VSDs is that when the motor is started, it starts out slowly and then increases speed over time while for single-speed drives, motors would abruptly start. Abruptly starting motors at max speed will deteriorate the life of motors as it puts a mechanical as well as an electrical stress on the motor. All of these advantages save

energy, prolong the life of the motor pumps, and reduce motor repair costs. It is stated

that VSDs can reduce a pump's energy consumption by as much as 50 percent, which

could save thousands of dollars or even more annually. While VSDs are reliable and easy

to operate, they do have the possible disadvantage of being expensive to install. The price

for a VSD depends on amount of horsepower that the motor performs. For a five

horsepower motor, the cost would approximately be $3000. For a custom made 300

horsepower motor, the price could be up to $45000. However expensive it may be, the

payback time of paying for the VSD installation can last anywhere from a few months to

a few years for 25 to 250 horsepower models (California Energy Commission, 2000).

The short payback time is a huge plus to using VSDs for any water treatment facility.

2.7.4 – Fine Bubble Aeration Mixing System

Used to promote bacterial growth in wastewater, aeration systems provide air by

mixing it with the wastewater. There are two common aeration systems that are used by

the treatment facilities, which are the mechanical system and the subsurface system

(Mcgee, 1999). The mechanical systems provide air by pushing the air from the

atmosphere and forcing it into the water using propellers and blades. On the other hand,

the subsurface system uses diffusers and any other devices placed in the water to pump

oxygen into the water. The disadvantage of using mechanical systems is the energy

amount used when compared to subsurface systems. For subsurface aeration systems,

there are coarse and fine bubble mixing systems with the latter becoming more popular

and replacing the coarse bubble diffusers. Fine bubble mixing systems, also known as

fine pore diffusion, are considered the most efficient approach for delivering oxygen in

wastewater treatment due to its high oxygen transfer efficiency. The fine bubble aeration

has many different types of diffusers, including three disc diffuser, tube/flexible sheath diffuser, plate diffuser, dome diffuser, and membrane diffuser.

Fine bubble aeration has a much higher surface area as it produces many small oxygen bubbles as well as having a slower rise speed to the surface in the wastewater versus larger bubbles produced by the coarse bubble aeration system (EPA, 1999). Because the aeration system of a wastewater treatment facility can consume anywhere from between half of the facility's power, upgrading the aeration system to become energy efficient is very beneficial. Not only is it efficient, but also it consumes little energy. The disadvantage of using this system is that it requires a lot of maintenance as it becomes dirty much easily and has high initial costs.

2.7.5 – Heat Recovery Systems

Heat recovery takes the energy within liquids or gases and reuses the energy for other purposes instead of letting it go to waste. The heat recovery process is accomplished by making use of a heat exchanger which exchanges heat from one source to another source. Heat recovery techniques include the use of air or water as the gas or liquid medium. First, for heat recovery from air, heat recovery makes use of heated old stale air or the hot exhaust to heat up fresh air. With this approach, the heat energy used in the old air or exhaust can be transferred to the new air, saving the energy needed to heat the air. There are a few drawbacks for these energy efficient systems, although these drawbacks can be easily accommodated for. One drawback is making sure that during the heating process, the two different air sources do not mix or leak, since mixing or leakage could result in a dangerous situation. Heat recovery is more effective for colder climates as the need to have ventilation of fresh air especially during the winter.

For heat recovery from water, heat recovery takes the discarded hot water and uses that heat energy for a variety of tasks such as heating the new fresh water. Annually, 235 billion kWh worth of recoverable energy from hot water is discarded through drains (Newton, 2011). The Department of Energy (US DOE) estimates that the energy lost in hot water is between 80 and 90 percent (EERE, 2005). Water heat recovery is only feasible if the community wastes sufficient amount of hot water that can allow for processing by the treatment facilities. Most of the hot water from residential households comes from showers and washing machines. By the time the hot water reaches the wastewater facility, it will relatively cool or lukewarm. However, because it is easier to heat lukewarm water than cold water, some energy is saved. There are three main types of heat exchangers used in the water and wastewater treatment facilities, which are shell and tube heat exchangers, spiral heat exchangers and plate heat exchangers.

A shell and tube heat exchanger is the most common type of the heat exchanger used for many different industrial applications such as fluid cooling, preheating, and evaporation. It is very efficient in recovering heat and designed to withstand high pressure (Ketema, 2007). Just as its name implies, the shell and tube heat exchanger consists of tube and shell cover where the heat transfer is made between fluids inside of the tube and outside of the tube. There are many configurations including u-tube heat exchanger and straight-tube heat exchanger although they operate based on a similar method: tube side and shell side fluid in, exchange heat, and out (Wenlock, 2011). The shell and tube heat exchanger is not suitable for handling sludge due to not being easy to clean. It is recommended to use the shell and tube heat exchanger for treated water heat

transfer. The unit price for the shell and tube heat exchanger can range from \$1,000 to \$20,000 based on the materials, size, and heat transfer capacity (Grainger, 2013).

A spiral heat exchanger is a counter current flow heat exchanger with two-spiral channel coiled one around another. Hot and cold fluids flow in opposite direction and exchange heat inside of the two channels where fluid cross contamination is not possible. Depending on the heat exchange and pressure drop requirements, the channel width may vary from a quarter to two meters, covering half to 278 square meter of area (Lines, 2013). Wide channel width of the spiral heat exchanger allows to effectively handle fluids containing sludge. Both sides of the heat exchanger are accessible that it is very easy to clean. Moreover, the spiral heat exchanger uses a self-cleaning mechanism where high fluid velocity due to fouled surface of the channel increases the fluid friction and thus scrubbing off the settled solids. Also, its counter flow arrangement makes it possible to achieve high thermal efficiency. The primary application of the spiral heat exchanger is to be used in anaerobic digester sludge heating. Digester sludge often contains about seven to ten percent of solid waste that tend to plug conventional heat exchanger (Lines, 2013). The temperature inside of the digester tank must be kept around 20 to 40 degree Celsius for mesophilic digestion (NRCS, 2003). This is done by heating the sludge with hot water that flows counter currently in the exchanger. To meet the requirements for a range of sizes and specifications, most of the heat exchangers are custom built. However, there are some small heat exchanger units available for general use.

A plate heat exchanger consists of several metal plates attached to four fluid carrying tubes and clamped   between fixed and movable head plates. In the plate heat exchanger, heat is transferred between cold and hot fluids counter currently to maximize

35

the thermal efficiency. The plate heat exchanger can be set up in a variety of configurations while occupying a very small amount of space due to its compact design. Like the spiral heat exchanger, cross contamination between two fluids is not possible and it is very easy to clean and maintain (Bengtson, 2010). The plate heat exchangers work efficiently for general fluid heating and cooling applications. They can be used for clarifier effluent cooling and heating recovery and building thermal control. Although this type of heat exchanger is economic and efficient to use, it has several limitations. The plate heat exchanger cannot handle high temperature difference between two fluids as well as other conventional heat exchanger units such as a shell and tube heat exchanger. Also, it has a potential for leakage and requires higher cost for pumping due to high pressure drop across the tubes (Alfalaval, 2010). The plate heat exchanger has a wide range of unit prices from $100 to $10,000 depending on the size, components, and heat transfer capacity (Grainger, 2013).

2.8 – Financial Support

2.8.1 – The SRF and ARRA

The SRF is a fund administered by the US to support water and sanitation infrastructures by providing low-interest time loans. In order to obtain the SRF loans, each water treatment facility has to apply and demonstrate the importance of the project. All projects eligible for the SRF are listed and prioritized based on the type, size, environmental impact, and other factors of the projects. There are currently two SRFs, the Clean Water State Revolving Fund (CWSRF) and the Drinking Water State Revolving Fund (DWSRF). Since 1989, the Massachusetts SRF has used about $2 billion for federal

grants and state matching funds to finance $6 billion worth of clean water and drinking water projects (Grossman, 2013).

The CWSRF provides loans to many different projects including wastewater treatment and collection projects, drainage improvements, landfill closures, brownfield remediation, and other non-point source projects. To date, approximately $89 billion was budgeted for the CWSRF to finance the water and wastewater treatment facilities and other green infrastructures for water quality projects throughout the US (EPA, 2013). Loan repayments are recycled back into individual CWSRF program with interest. The CWSRF can provide 100 percent of the project cost with 20 years of repayment period (Perez, 2012). The interest rate for the CWSRF loan is only two percent which is half of the market interest rate of 4 percent. In fact, a CWSRF funded project would cost 19 percent less than the project funded at the market rate (EPA 2013). Debt service on the SRF bonds is paid from 3 sources which are interest earning from the borrower, the debt service reserve, and the subsidy payments provided by the Commonwealth (Grossman, 2012). The CWSRF is expected to grow over time as interest earnings and repayments of loans continue to increase. In fact, about 18 percent of the CWSRF revenue is from the interest earning.

In 2013, the CWSRF expanded the program by providing $186 million to additional 46 borrowers, out of which, 15 were for the Community Septic Management Program (CSMP). Financial supports for eligible projects are provided through the Interim Loan Program with monthly interests whose interest rate is set at half of the one-year Massachusetts Municipal Depository Trust (MMDT) rate. In FY 2013, about $118 million was used to fund 79 projects though the Interim Loan Program with an average

interest rate of 0.13 percent (Grossman, 2013). Extended financing for the program is also available for the projects that have at least 30 years of pay back periods.

In 2009, the American Recovery Act (ARRA) was passed and budgeted $4 billion to provide financial supports to the drinking water and clean water projects. The ARRA included new options to CWSRF programs such as the Green Project Reserve (GPR). It was quite successful and many projects received benefits from the ARRA through the GPR. The ARRA provided around $133 million in each year from 2009 to 2012. However, about 87 percent of the ARRA funds were used by end of 2011 and the ARRA related funds and workloads decreased significantly in 2013 (Babauta, 2013). Hence, it is hard to expect funding from the ARRA at this point.

Like the CWSRF, the DWSRF provides loans to finance water quality projects with low interest rates and long and flexible repayment periods. The Division of Municipal Services of MassDEP and the Massachusetts Water Pollution Abatement Trust administer the DWSRF. Every year, the program operates with approximately $125 million to fund engineering, designing, and constructing the water and wastewater treatment projects (Riedell, 2010). The sources for the DWSRF revenue are the borrower repayment, the interest earning, and the Commonwealth contract assistance. In 2013, about 73.6 percent of the DWSRF revenue comes from the borrower repayment, 13.9 percent from the interest earning, and 12.5 percent from the contract assistant (Grossman, 2013).

In 2012, the DWSRF program was expanded by funding $119.7 million for 35 water treatment projects. Series 16 Pool Program Bonds were also issued in June 2012 and provided $98.8 million in 25 drinking water loans (Grossman, 2012). These loans

have time limits of two years during which the borrowers have to spend the project funds. In 2013, the DWSRF program funded 16 projects with $40 million. This is a significant decrease from the previous year's budget. In addition, Interim Loan Program provided $46.6 million to 35 projects with an average interest rate of 0.13 percent. Generally, the DWSRF does not require the Green Project funding. Nonetheless, the green projects are identified in the Drinking Water Project Benefits Reporting System (PBR) and financed through the DWSRF (Grossman, 2013).

2.8.2 – Solar Energy Opportunities

Solar Carve-Out SERCs is a program to support residential, commercial and public, and non-profit entities in developing 400 MW of PV system across the Commonwealth of Massachusetts. In order to participate in this program, the PV system must have a capacity of 6 MW or less per parcel of land, be located in the Commonwealth of Massachusetts including municipal light district territories, use some of its generation on-site, and be interconnect to the utility grid. Projects that have received funding from programs administered by MassCEC or Renewable Energy Trust prior to the start date of the Solar Carve-Out Program in January 1, 2010 or those that received substantial funding from the American Recovery and Reinvestment Act (ARRA) federal stimulus programs are not eligible to participate in the program (Mass EEA, 2013).

Commonwealth Solar II is a project that provides rebates for homeowners and businesses across Massachusetts who installs solar PV. The rebate is granted thorough a non-competitive application for the installation of PV projects by licensed and

professional contractors at residential, commercial, industrial, institutional and public facilities. Additionally, further incentives are available for using components built in Massachusetts. The rebates are generated by multiplying per watt incentive times the nameplate capacity up to 5 kW of the system. Projects are only eligible if the total capacity is under 15 kW. The base incentive is $0.40 per watt, Massachusetts company adder is $0.05 per watt, and natural disaster relief adder is $1.00 per watt (Mass CEC, 2013).

Leasing the solar system could be another option for the solar PV installation opportunities, especially when the project does not qualify for any of the financial aid programs. The biggest benefit for leasing the PV systems is that the monthly payments may be lower than the previous utility bill, resulting in immediately saving. And the saving benefitted from solar energy will continuingly increase throughout the entire term. The lease provider will take care of the maintenance for twenty years, since they are the owner of the system, on the other hand, the leaser will not be able to get any rebates, incentives or RECs. At the end of the lease term, the final cost for the user is about two to three times, more than the cost it would be to install and maintain the solar system. Leasing is a good way to go solar, savings will be resulted immediately, and the better investment is to purchase the system, especially when cash flow is not the primary objective (AMECO, 2013).

2.8.3 – Wind Opportunity

Commonwealth wind program is offered by MassCEC. MassCEC assists wind energy development in Massachusetts that can help achieve the goal for clean environment and a strong economy. The Commonwealth wind project has been

supporting electric customers and the wind development community since 2000. The commonwealth wind program supports small wind, community wind and commercial wind projects. The small wind project utilizes wind turbines with power capacity less than 100 kW. Community wind is a wind project that utilizes one or more wind turbine with power capacity of more than 100 kW serves a load located on the project site which will have net-metering agreement with the utility company or will serve the load requirements of a host municipal light department. Commercial wind is a project serves the ISO-New England wholesale electricity market or a municipal light plant system. Site assessment grants of services, feasibility study grants and development grants, development grants will be available for both community and commercial wind projects. In addition, there will be rebates for the small wind construction based on the turbine-rated capacity and expected production (MassCEC, 2013).

2.8.4 – Hydropower Opportunity

Commonwealth hydro program is offered by MassCEC. The major three projects focused by this program are upgrades to federal energy regulatory commission (FERC)-licensed facilities that will result in greater generation, developments of new hydropower plants that make use of the water flowing in artificial conduits such as the water distribution system, and modifications to the facilities on FERC-licensed canals. Meanwhile Commonwealth hydro program is limited to the projects that will demonstrate a high possibility of qualifying for the Massachusetts renewable energy portfolio standard. Only projects implementing commercially available technologies are eligible for this funding program which has an available fund of $1,200,000. Grants for eligible projects will be limited to less than $600,000 or 50 percent of the actual project cost, or

$0.025 for every kWh increased after upgrades. Also, grants for feasibility studies will be less than $40,000 or 80 percent of the cost. The maximum grants can be calculated as follows (MassCEC, 2013).

$$\textbf{Incremental kWH per year} \times \textbf{20 years} \times \$\textbf{0.025} \leq \$\textbf{40,000 whichever is less}$$

2.8.5 – Biomass opportunity

Commonwealth Organics-To-Energy program provides funding to educate business and communities about biomass to energy technologies and help them to evaluate biomass projects and support constructing the facilities. The projects must be located in the service area of the electric distribution companies under the Massachusetts Renewable Energy Trust Fund administered by the MassCEC (EPA, 2013). The electricity produced must be eligible for the Mass Renewable Portfolio Standard. The major technology supported by this program is anaerobic digestion although limited amount of award may be made for projects using other available technologies. In order to apply the grants, the construction projects must implement proven technologies with expected life for the structure and equipment of 20 years. Moreover, the projects should be economically viable. The maximum amount of the grant provided by this program is $400,000 or 25 percent of total project cost whichever is less (MassCEC, 2013).

2.8.6 – Tax Incentives

Tax incentives for private reinvestment in renewable energy, there are three kinds of incentives suitable for the ZNE project. The facilities that produce electricity from solar power will be able to get 30 percent of an investment tax for the next years' service. Facilities that produce electricity from wind, biomass, and hydropower are eligible for a

production tax credit which should be payable within ten years (EPA, 2009). The estimated budget of the tax incentive program is $285 million over ten years. Clean renewable energy bond authorizes $1.6 billion of new clean renewable energy grants to finance facilities that generate electricity from wind, biomass, hydropower. The total of $1.6 billion grants will be divided into three parts: one thirds of it will be used for qualifying projects of state, local, and tribal government, one-thirds for qualifying projects of public power providers, and the rest for qualifying projects of electric cooperatives (Hatch, 2009).

2.8.7 – Renewable Energy Certificates

Renewable Energy Certificates (RECs) are tradable energy certificates that can be sold. A REC is provided to a facility that is generating green energy. One REC is given out to a particular facility for every 1,000 kWh of clean energy that it produces. The purpose of the REC is to make it so people who do buy the RECs is equivalent to them supporting the green energy projects directly by providing financial support and claiming that they are "buying" renewable energy. Because the green energy that was produced is mixed with conventional energy, consumers cannot easily choose which electricity to buy so RECs was created to solve this problem. Once a certificate is purchased and used, it cannot be used again. Each time a certificate is sold, some of the new renewable energy projects can be built such as the energy projects that can be built at these water and wastewater treatment facilities (EPA, 2008). The REC prices are based on market conditions (supply & demand).

Table 2. Annual Renewable Energy Certificate Rate (DiBara, 2014)

Renewable Energy Option	REC Rate*
Solar PV System	$0.20/kWh (first 10 years) $0.03/kWh (next 10 years)
Wind Turbine	$0.03/kWh (20 years)
Hydropower turbine	$0.025/kW (20 years)
AD and CHP system	$0.03/kWh (20 years)

*Estimated REC rates reflect the assumption that were used in the economic analysis

2.8.8 – Additional Grant Opportunity

The American Recovery and Reinvestment Act of 2009 (ARRA) provided a very unique opportunities to municipal water and wastewater treatment facilities. To promote better energy efficiency and clean energy usage, MassDEP and MassDOER collaborated to open more incentive opportunities to support facilities that are considering system efficiency upgrades and renewable energy generators. A total of $1,500,000 is available and provided through the Regional Greenhouse Gas Initiative (RGGI) and Alternative Compliance Payments (ACP). Only municipal or district water and wastewater treatment facilities are eligible for the project and any project with project cost under $100,000 will be fully financed through the program. This opportunity will be open in April 16th, 2014 and receive the application until April 23th, 2014. Awards will be first come, first served basis and the maximum grant for each facility is $200,000. Following is a brief summary of eligible projects for this grant opportunity (Claeys, 2014).

- Energy efficiency projects
- Renewable thermal energy projects, including water, wastewater or air-sourced heat pumps, and solar thermal
- In-line micro hydropower turbines
- 15% project cost of a facility owned solar PV system with less than 200 kW capacity
- Combined Heat and Power (CHP) projects

2.9 – Background Summary

Water and wastewater treatment facilities require a vast amount of energy to treat and distribute water to local communities. In order to reduce the energy consumption and air emission, MassDEP is working its way through to identify the energy efficient options at the water and wastewater treatment facility. Developing and implementing the energy improvement plan requires a thorough economic and environmental analysis in order to identify the most cost-effective, clean, and feasible energy improvement options. Both energy efficiency and renewable energy must be developed concurrently to reduce energy consumption and achieve sustainable energy. Certainly, there are many energy efficient systems currently available and many facilities see great benefits from installing them.

3.0 – Methodology

The overall goal of this Interactive Qualifying Project (IQP) is to develop a plan to increase energy efficiency and reduce energy consumption at three treatment facilities: one drinking water treatment facility and two wastewater treatment facilities. By achieving this goal, these facilities will have more opportunities to pursue energy independence and save money. In this chapter, the objectives that the team will perform are outlined below.

- Receive the assigned drinking water and wastewater treatment facilities for the project participation

- Conduct background research and contact facility owners and operators to confirm their project participation

- Visit facilities and collect additional data

- Determining Potential Renewable Energy Options

- Develop an economic summary for each facility

- Develop a brief environmental summary regarding amount of CO_2 reduced

3.1 – Receiving Facilities for the IQP

MassDEP identified and provided three facilities with potential in energy reduction and cost savings to the WPI team for the IQP. The selected facilities were the Pepperell Wastewater Treatment Facility, the Millis Drinking Water Facility, and the Southbridge Wastewater Treatment Facility. Moreover, MassDEP provided energy audits and other information regarding these facilities for energy assessments. The final report for each facility was submitted after a thorough economical energy assessment has been completed.

3.2 – Conducting Background Research

With the three facilities selected, necessary background research on the facilities were performed to determine what energy efficient upgrades and renewable technologies are available to benefit the facility. For this IQP, the team focused on the four main renewable energies which are solar power, wind power, hydropower, and biomass. The renewable sources available at the plant site were identified and evaluated using Geographic Information System (GIS) data on solar, wind, and biomass provided by the NREL. Moreover, results from benchmarking tools such as EPA's ENERGYSTAR Portfolio Manager and MassDOER's MassEnergy Insight regarding the facilities were analyzed. These tools provided useful data that display the trend of the facilities' energy consumption and costs. Energy audits provided by MassDEP already provided energy reduction plans with energy efficiency measures of each component of the facility. Therefore developing the energy reduction plans is ranked lower than the renewable energy options on the team's priority list.

3.3 – Visiting Facilities and Collecting Data

After MassDEP finalized a working date with each facility for the site visits, the team visited each facility and collected important information for further analysis that could not be found through simple background research. The data that was collected included, but is not limited to, current energy usage, energy efficiency, energy costs, size/location of facility, current technologies being used, and actual usable land. The data collected from the site visits will complement data obtained earlier from background research and aid the team in deciding what upgrade and renewable technology would be the most practical.

3.4 – Conducting Renewable Energy Assessment

Each renewable energy technology has many requirements to be feasible and efficient. However, it is hard to satisfy all the requirements due to limited amount of renewable resources and available area at the site. To implement the renewable technology effectively, it is crucial to determine and rank the available resources and area according to their abundance and size. Overall, solar power, wind power, hydropower, and biomass assessments take similar steps in determining their feasibility.

3.4.1 – Solar Power

When performing the solar power assessment of the facility, many factors were accounted for. Two important factors that decided the overall power output of the PV system were the average solar hours each day as well as the area of the solar PV system. GIS maps provided the annual solar insolation in Massachusetts while the area was calculated by using Google's satellite images. Available area for the project was confirmed during the site visit where the facility managers provided information on available area at the site for solar project. The team checked possible ways of implementing the solar arrays either ground mounted, roof mounted, or a combination of both. The following formula was used to calculate the annual energy output of the system with an assumption of 80 percent of area efficiency.

$$\textbf{Energy (kWh)} = \textbf{area}\left(\textbf{m}^2\right) \times \textbf{efficiency} \times \textbf{insolation}\left(\frac{\textbf{kWh}}{\textbf{m}^2}\right) \times \textbf{performance ratio}$$

With the energy of the PV system calculated, the capacity of the system was determined by dividing solar hours per year and the performance ratio of the panel. The maintenance

fees and other operational fees were taken into account when calculating the cash flow of the PV system. If the system produced sufficient energy to pay the project cost back within a short amount of time as well as results in a significant energy reduction in the facility, it would be highly recommended to install the system.

3.4.2 – Wind Power

The wind power assessment followed a similar method as the solar power assessment. One of the most important factors in determining the practicality of constructing wind turbines was the wind speed at the site. Minimum operating wind speed for wind turbines is 10 mph. For the wind turbine to be efficient, the wind speed must exceed 14.5 mph and be at least 30 m above the ground. NREL GIS maps provided the data on the wind speed profiles at altitudes of 30, 50, 80, and 100 m in Massachusetts. The power output of the wind turbine depended on the rotor diameter and average wind speed. Following is the power output equation for the wind turbines from NREL.

$$\textbf{Output } (\textbf{W} \cdot \textbf{h}) = \textbf{0.01328} \times \textbf{rotor diameter}(\textbf{ft})^2 \times \textbf{wind speed}(\textbf{mph})^2$$

The value obtained from the equation was verified with the energy output curve of the wind turbine.

To make the calculation easier, small wind turbine systems with an average rotor diameter of 20 m was used for analysis since the selected water and wastewater treatment facilities are relatively small. In addition to estimating power output, the available project area needed for the project determined by using Google maps area calculator. The wind turbines usually have to be placed at least 90 meters away and six meters above any

49

nearby building to receive uninterrupted wind. If the facility satisfies all of these

requirements, the wind turbines could be built at the site. Moreover, the project cost of

the wind turbine was calculated with 30 percent engineering cost.

3.4.3 – Hydropower

When performing the hydropower assessment of the facility, the amount of head

and water flow rate is important when considering hydropower. The hydropower turbine

has to be installed in the effluent pipe rather than the influent pipe to prevent residue

accumulation unless the influent is as clean as the effluent and has high potential for the

hydropower. Hence, the effluent water flow rate was measured along with the total

available head in the facility. Since most of the wastewater treatment facilities have low

available heads, it is recommended to install an in-line reaction hydropower turbine. The

power produced by a reaction turbine with efficiency e in water with density ρ and

velocity V through a cross-sectional area A is:

$$\textbf{Power (kW)} = \frac{1}{2}\textbf{e}\boldsymbol{\rho}\textbf{AV}^3$$

For drinking water facilities that have relatively high heads and slower flow rates,

installation of impulse turbines is recommended. The power generated by an impulse

turbine with efficiency e, head H and flow rate Q is

$$\textbf{Power (kW)} = \frac{\textbf{Head (ft)} \times \textbf{Flow (cfs)}}{\textbf{11.8}} \times \textbf{efficiency}$$

In some facilities, both the head and the flow rate are low, so neither impulse nor reaction turbines are suitable for use; in this case, a Pumps-as-Turbine (PAT) systems are the best choice. The power capacity for a PAT system can be calculated as…

$$\textbf{Power (W)} = \textbf{5} \times \textbf{efficiency} \times \textbf{head (meters)} \times \textbf{flow (lps) (PAT)}$$

The average efficiency of a conventional hydropower turbine is about 75 percent, and the capacity factor is around 75 percent (Lalander, 2010).

For the hydropower analysis, a virtual site screening with Google maps or GIS maps data cannot provide much data. Therefore, the data were obtained from pipeline plan and from site visits. The hydropower turbine are usually customized, the cost is determined by the head, the flow rate, and the sites to be installed.

3.4.4 – Anaerobic Digestion

Performing the anaerobic digestion (AD) assessment depended on a few primary factors, which included the amount and type of the biomass produced at the site or nearby the site. AD could be implemented at wastewater treatment facility due to high biomass production. The usable part of biogas generated from the biomass was around 60 to 70 percent, out of which only 30 percent could be converted into electricity. For the analysis, the AD system was coupled with the CHP to maximize energy output and recovery rate, for the CHP has a recovery efficiency of about 75 percent. The biomass produced more biogas when it was mixed with the food waste or other materials with high levels of organic content. Hence, having a large dairy farm, or industrial processing facility generating consistent streams of organic materials nearby, and a good transportation

51

network to the facility increased the positive economic potential for biogas production for a facility with digesters.

The site assessment and feasibility study were conducted using Google maps and information provided by the facility. Google maps provided a detailed site screening for the available project area and transportation to the nearby the dairy farm and landfill. Information on the facility's annual sludge production was used to determine the total energy output of the AD system, which was then used to calculate annual electricity and heat production. Afterwards, the size of the CHP was found using the total energy output to determine the most optimal CHP option. The project cost of the AD and CHP was estimated based on the assumption that the system was co-digestion.

3.5 – Developing an Economic Summary for each Facility

Based on the data obtained from the field investigations and simulations, an economic analysis was performed for the chosen renewable technologies and upgrades for each facility. This economic summary contained information including potential project costs, incentives, annual energy savings, loans, and total cash flow of the project for each participating facility.

The project cost of the PV system depends on the number of solar panels that can be mounted on a given area. However, to make this calculation easy, the team assumed that a PV system would cost around $4,000 per kilowatt produced. Same type of analysis was applied to wind and hydropower turbines. Although both turbines had various unit prices depending on different models, $3,000-5,000 per kilowatt and $8,600 per kilowatt were used to estimate the project cost of the wind and hydropower turbines, respectively, for easier calculation. The overall capacity of the renewable system was found by converting the total energy output (kWh)

calculated in the previous section into kW. Once obtained, the overall capacity was multiplied by the price rate of corresponding system to estimate the project cost. For the AD and CHP, the project cost could not be determined as simply as the solar PV, wind turbine, and hydropower turbine. They are mostly custom built and it was necessary to contact the company with detailed specifications or use similar case studies and reports to approximate the project cost.

Available amount of the incentives for each type of renewable technologies was estimated based on the grant information provided by MassDEP, MassCEC, and MassDOER. Moreover, 20 years period loan with two percent interest was applied to each project to breakdown the total project cost and allow positive cash flow.

The total cumulative cash flow was the final thing to consider when concluding whether the project was economical. The total cumulative cash flow is the sum of the difference between the anticipated savings and the loan payment period. The anticipated savings included savings from the annual REC, energy efficiency upgrades, and on-site generation. The loan payment included the 20 years loan for the implementation of renewable technology and the 2.5 years zero interest loan from National Grid for the efficiency upgrades. To maximize the cash flow, it was crucial to achieve large savings and incentives and low project cost. If a certain renewable energy technology had significantly high cash flow, then that would be the best option for the facility, for it saved more money for the next potential project. With all of these data provided in results section, the facilities would be able to make smart choices on what to upgrade and implement to reduce energy usage and annual costs.

3.6 – Developing a Brief Environmental Summary for each Facility

In addition to the economic summary, the team also made a brief environmental summary as an addition to show the amount of CO_2 reduced if the project were to be pursued by the facility. This summary covered the GHG emissions. The GHG emissions is calculated by simply taking the product of the overall power output and the amount of CO_2 generated which was 909 grams if it was coal while for natural gas, it would be 465 grams per kWh of energy produced.

4.0 – Results

The goal of this project was to determine whether any potential energy efficiency upgrades and renewable energy generation alternatives could to reduce the energy consumption and ultimately, reach the zero-net energy use for a set of three trial water and wastewater treatment facilities. The three facilities analyzed in this report include the Pepperell Wastewater Treatment Facility in Pepperell, MA, the Southbridge Wastewater Treatment Facility in Southbridge, MA, and the George D'Angelis Water Treatment Facility and associated water treatment system in Millis, MA. The renewable energy recommendations for the for the three water and wastewater treatment facilities was developed in collaboration with Massachusetts DEP, and Departments of Public Works for the corresponding towns. The results of the analyses are provided in the following sections.

4.1 – The Pepperell Wastewater Treatment Facility

The Pepperell Wastewater Treatment Facility was built in 1980 to treat wastewater from the towns of Groton and Pepperell, Massachusetts. The facility has eight pump stations, eight generators, 30 pumps with various sizes and models, five air blowers, 28 pump controllers, three UV disinfection units, and other types of mechanical and electrical treatment equipment (Pepperell Department of Public Works, 2012). Although the facility was designed to treat 1.13 million gallons per day (MGD), it currently treats 540,000 gallons of wastewater and 3,000 gallons of septage every day from 1,850 customers. Figure 8 shows a satellite view of the facility located at 47 Nashua Road, Pepperell, Massachusetts.

Figure 8. Pepperell Wastewater Treatment Facility Satellite View (Google Maps, 2014)

The annual revenue of the Pepperell Wastewater Treatment facility is around $2 million, over 60 percent of which come from Groton and Pepperell usage charges. The debt has increased by 70 percent since 2008 and the facility is considering to increase the rate for the Pepperell and

Groton Sewer by three percent. Detailed sources of the facility's annual revenue can be seen in Figure 9.
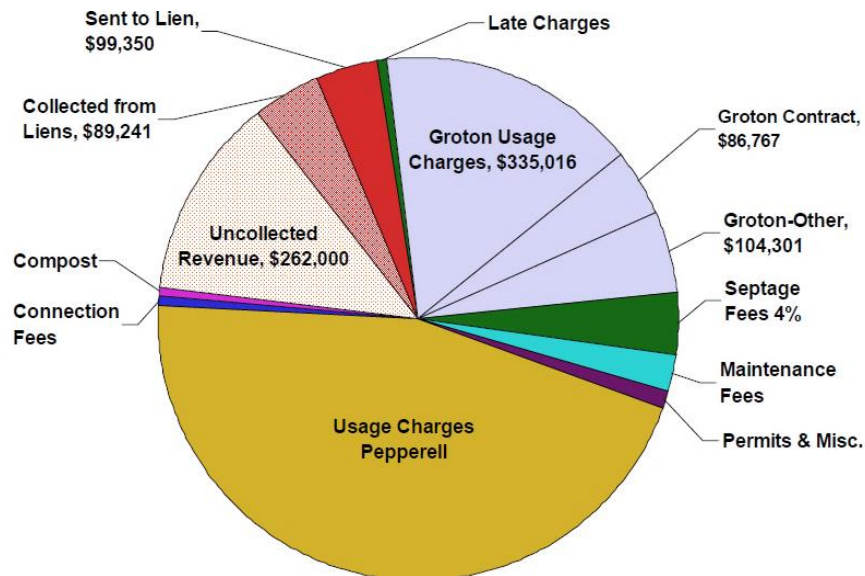
Figure 9. Pepperell Wastewater Treatment Facility Annual Revenue (Stevens, 2008)

4.1.1 – Wastewater Treatment Process

The Pepperell Wastewater Treatment Facility is a small plant that implements an extended aeration wastewater treatment process. The main components of the treatment process are a grinder, grit removal chamber, fine bubble aeration tank, secondary clarifiers, and ultraviolet (UV) disinfection unit.

Influent wastewater stream transferred by the pumping stations enters the grinder, which reduces the size of the solid particles in the wastewater stream to about a quarter inch. The wastewater stream goes through two wet wells and a grit removal chamber where grits are removed from the stream. Afterwards, the waste stream flows to the aeration tank, which has a detention time of 24 hours. After the aeration tank, the wastewater enters the clarifier and passes through the UV disinfection units before it is discharged to the Nashua River. A portion of the sludge removed from the clarifier is recycled to the aeration tank, or stored in the aeration tank or

the aerated sludge storage tank. A detailed schematic diagram of the facility's operation process is shown below in Figure 10 (Jones, 2012).
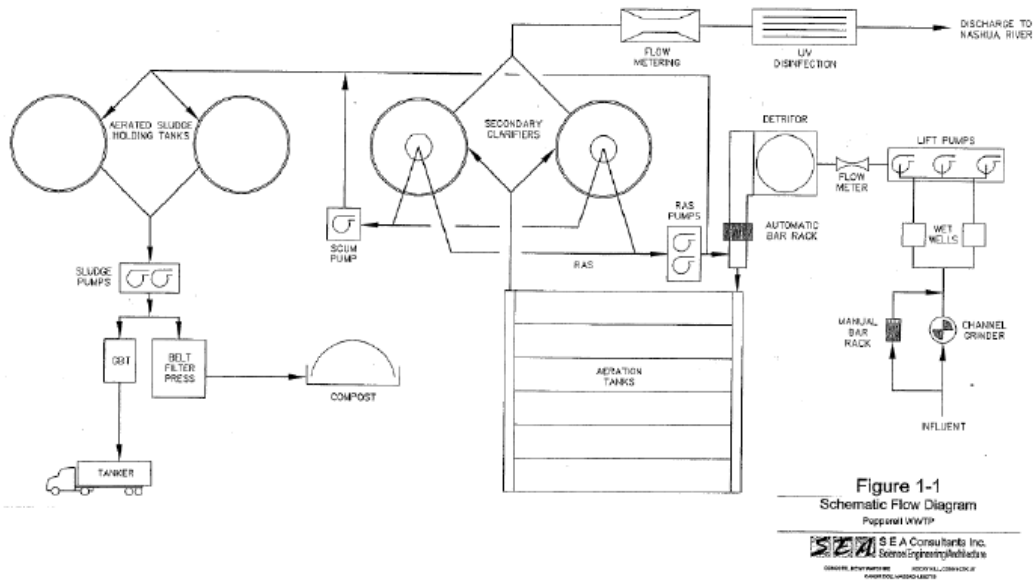
Figure 10. Pepperell Wastewater Treatment Process Diagram (Jones, 2012)

4.1.2 – Current Energy Use of the Facility

In 2012, the Cadmus Group, Inc. conducted a thorough energy audit to identify options that could improve energy efficiency and reduce GHG emissions at the Pepperell Wastewater Treatment Facility. Figure 11 represents the monthly energy consumption of the facility over five years, a part of the Mass Energy Insight results from the audit. The EPA Portfolio Manager Tool was not used to benchmark the facility since it is not designed to benchmark efficiency of small water and wastewater treatment facilities with water flow rate less than 0.6 MGD (Turgeon, 2013).
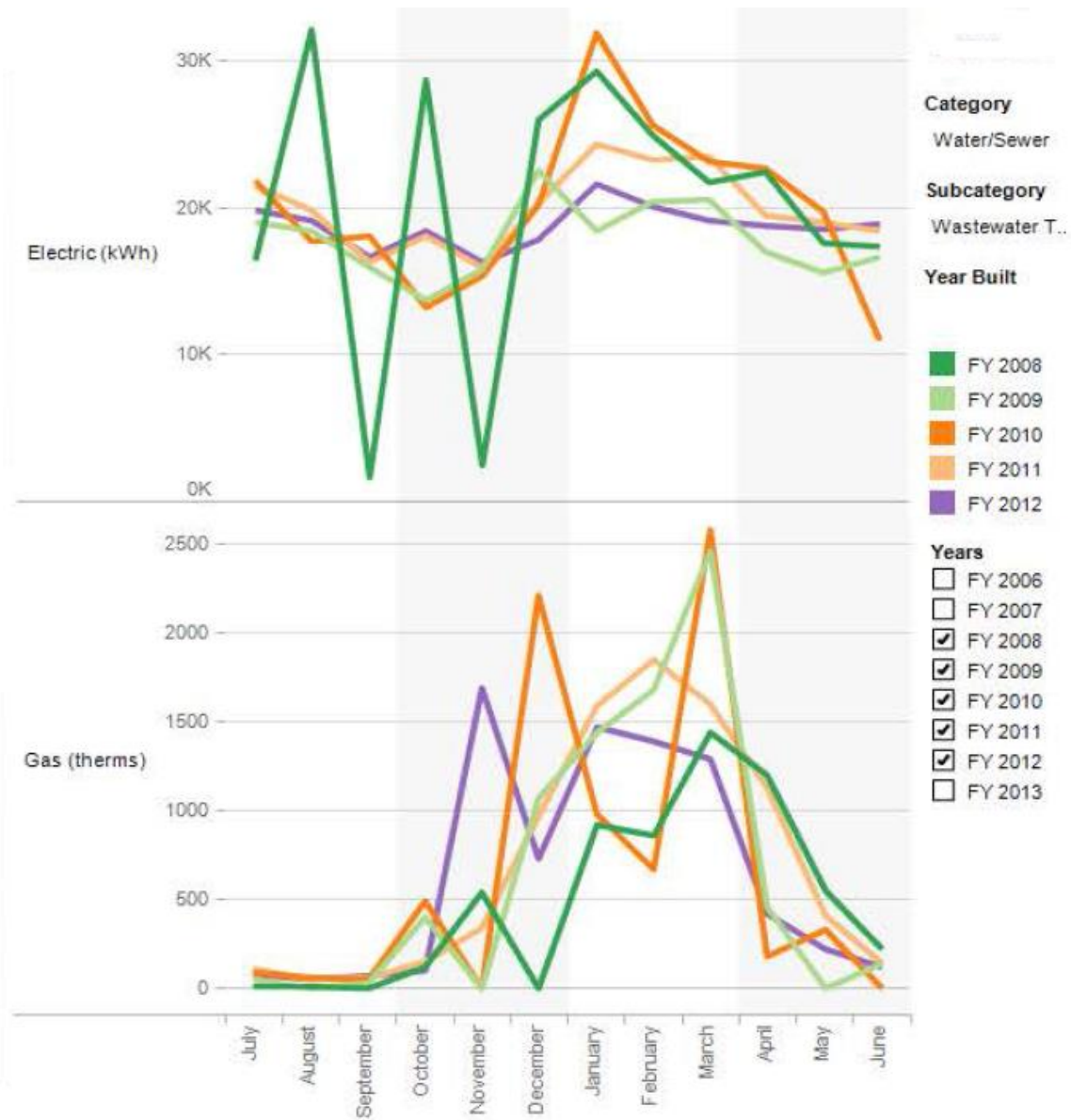
Figure 11. Annual Electricity and Gas Consumption (Jones, 2012)

The Pepperell Wastewater Treatment Facility consumes over 210,000 kWh of electricity and 8,000 therms of gas annually. Electricity is consumed consistently throughout the year, reaching its highest point in January. On the other hand, gas is consumed mostly during the winter because it is used exclusively for comfort heating. The facility's electric consumption data for two months in 2008, September and November, are missing and the usage pattern of 2008 does not seem to follow the general usage trend of four consecutive years. In fact, unlike every

other years in the data record, the facility used a significant amount of energy in August and October in 2008. Moreover, the energy audit estimated the facility's average daily electricity use to be 1,077kWh, which is almost twice of its' reported daily use. The Cadmus Group, Inc. suggested that there might be some problem with the billing meter or an additional feed to the plant (Jones, 2012).
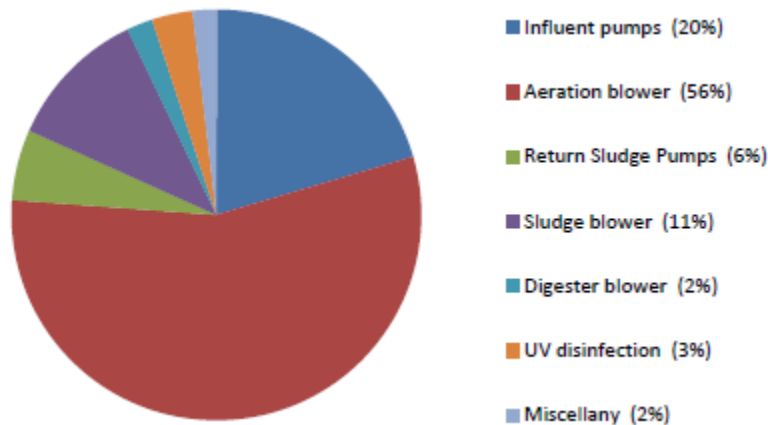
Figure 12. Breakdown of the Facility's Energy Consumption (Jones, 2012)

Figure 12 shows the electric consumption for various types of equipment. As shown in this figure, the majority of the facility's electricity use is associated with the pumping and aeration process which together comprise of 82 percent of the total electricity use. Hence, it is crucial to improve the efficiency of the pump and aeration system to achieve a significant energy reduction.

The Pepperell Wastewater Treatment Facility purchases electricity and natural gas from National Grid at an average cost of $0.141/kWh and $1.337/therm, respectively. The facility's annual gas cost decreased from $13,000 to $6,000 since 2009 due to a decline in natural gas price. On the other hand, the annual electricity cost since this time remained constant around $32,000.

4.1.3 – Efficiency Potential

The Cadmus Group, Inc. conducted energy audits on the facility and provided efficiency improvement options and other recommendations. Following is a summary of the energy audit results and recommendations (Jones, 2012).

- Operate two wet wells as one instead of operating them independently to increase the capacity of the wet wells. The increased capacity will allow longer on and off period of the influent pumps to save energy.

- Increase the minimum speed of the main lift pumps to increase the pumping efficiency and rate. The main list pumps operate at a very low efficiency of 50 percent. They need to be checked and repaired to restore their designed efficiency of 80 percent.

- Control the VSDs to operate the RAS pumps with minimum speed to meet the flow requirements to the activated sludge and the aeration basin.

- Install small pumps for low influent flow to minimize on and off cycle of the pumps. The main lift pumps have a pumping capacity of 1500gpm while the average influent flow rate is only 375gpm. Hence, it is practical to use smaller pumps to handle low flow rates.

- Upgrade the lighting systems from T12 lamps to T8 lamps to achieve higher efficiency.

- Install a primary and secondary (master/slave) control system to control the valves with DO sensors and the blowers with air pressure.

- Replace the existing Roots blower with a K-Turbo blower, which increases the blower efficiency by 10 to 20 percent.

- Upgrade the existing pumps with NEMA[5] Premium[TM] efficiency motors. This option has lower priority because the existing pumps have similar efficiency as the recommended pumps.

- Replace natural gas boiler with a condensing or pulse-combustion boiler. This option has the least priority since the facility does not depend on gas as much as electricity.

Once implemented, the facility is anticipated to save approximately $23,694 annually with an estimated installation cost of $109,114. Average payback year for this modification project is around 2.5 years with a total potential incentive of $48,821. Moreover, a 2.5-year term National Grid In-Bill Financing loan with no interest is applied to cover up the project cost. A detailed economic summary of the audit can be found in Table 3. Disregard the annual savings of $19,778 and potential incentive of $17,950 in the chart since the updated values are provided above.

Table 3. Cadmus Audit Economic Summary (Jones, 2012)

Energy Conservation Measure #	Recommended Action	Annual Electric Savings (kWh/yr)	Annual Natural Gas Savings (therm/yr)	Annual Savings ($/yr)	Implementation Cost ($)	Potential Incentives ($) *	Net Payback (yr)
Operational Measures							
1	Operate the two wetwells as one	1,739		$245	$0		Immediate
2	Increase speed and decrease operation of Main Lift pumps**	21,820		$3,068	$0		Immediate
3	Open Valve(s) and Slow Down RAS Pump(s)	4,548		$640	$0		Immediate
Capital Improvement Measures							
4	Overhaul main lift pumps**	12,469		$1,753	$ 6,000		
5	Install small influent pump **	20,622		$2,900	$ 25,000	$ 17,500	2.6
6	Install Energy Efficient Lighting	3,154		$443	$ 1,710	$ 450	2.8
7	Add Dissolved Oxygen probes and automate blower control	60,569		$8,517	$25,188		3.0
8	Install "Turbo" style blower	43,576		$6,128	$51,216		8.4
Total Savings (Including Interactions) **		140,653		$ 19,778	$ 109,114	$ 17,950	4.6
Measures Considered (Not Recommended)							
9	Install premium efficiency motors						
10	Replace Natural Gas Boiler		239	$319	$ 12,900	$4,000	38.1

* Incentives available through MassSave. Prescriptive incentives listed; Custom process incentives may also be available for custom projects to buy down to 1.5 year payback or up to 70% of incremental cost.

** For ECMs 1-7, each measure assumes implementation of previous measures for the purpose of accounting for interaction among measures. ECMs 7 and 8 are presented independently but their combination is included in the total, which is why the total savings does not equal the sum of the measures' savings.

In addition to the specific, quantified measures listed above, Cadmus also recommends installing flow meters at wastewater pumping stations. This will allow Pepperell staff to collect data from which pumping effectiveness at the various stations could be determined. This could lead to additional energy savings opportunities being identified in the future.

4.1.4 – Solar Potential

The Town of Pepperell is marked with blue in the GIS solar map in Figure 13. Just like any other parts of Massachusetts, the Town of Pepperell receives annual PV solar ration of 4 to 4.5 kWh/m^2 per day. The Pepperell Wastewater Treatment Facility is a small facility where a large PV system cannot be built. Indeed, only a small part of the facility is available for ground mounting for the PV system. Roof mounting is also an option at this facility since most of the structures built after 1970s are designed to support loads far greater than two kilograms per square meter, which is a combined weight of the solar panels and the rack that supports the panels (Turnia, 2012). As shown in Figure 14, the facility has two areas where the solar panels can be built. Taking account of the abutting industrial zoned lot that the town is considering to purchase, the facility has approximately 1,823 m^2 for ground mounting and 373 m^2 for roof mounting. If the compost area could be cleared, the facility will have significantly more area for the PV system, adding over 2,700 m^2 to currently available area.
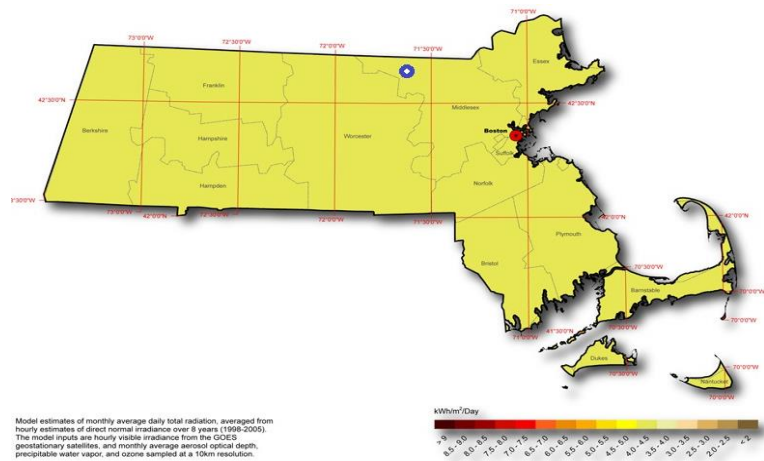
Figure 14. Available Area for Solar PV (Google Maps, 2014)

The maximum energy output that can be generated annually from the available area is 541,039 kWh with 20 percent PV efficiency and 75 percent performance ratio (Fthenakis, 2011). The facility only consumes less than half of the maximum energy output that could be generated from the available area. To cover the annual energy consumption of the facility, the solar panels should have a total area of 850 m^2. Since the area efficiency of the solar panel is around 80 percent, the total project area of the proposed PV system should be at least 1063 m^2 (Green, 2011).

To generate 210,000 kWh, the PV system should have a capacity of approximately 170 kW. The required capacity of the PV system may increase or decrease depending on its performance ratio. Assuming that the PV system costs around $4.0 per watt generated, a 170 kW PV system would cost around $680,880, assuming the system was designed and operated by the town. The 170 kW PV system will cover 100 percent of the facility's energy consumption, resulting anticipated annual saving of $29,610. Operational and maintenance fees were taken into account as well. These fees include an annual service of data acquisition system monitoring and data upload for the solar arrays, maintaining the land such as mowing the grass that the solar

arrays are situated on, replacing the inverter once every decade, and optional monitoring and testing the solar panels and other various related equipment. The maintenance cost varies depending on the size of the solar array and services. The maintenance cost over 20 years is calculated to be $47,000 with average maintenance cost of $2,350 per year.

The total cumulative cash flow from energy installation projects is $865,680 with 20 years period loan with two percent interest and $0.2/kWh (first 10 years) and $0.03/kWh (next 10 years) REC rate. Without energy efficiency upgrades, the facility saves the total cumulative cash flow reduces to $391,800.A detailed calculation for the economic analysis can be found in Appendix B. The cash flow of the PV project is demonstrated with Figure 15. A black line indicates the cash flow of the solar PV system without considering the efficiency upgrades.

Another way to adapt solar PV system is to lease the whole system through a third party ownership, in this way the facility only need to pay the contractor for the electricity generated from the solar PV system. Under the contract, the service provider will install and maintain the system and the facility can either buy or renew the lease at the end of the contract. These agreements are known as Power Purchase Agreements (PPA). Solar Power Purchase Agreement is a long-term agreement between an energy developer and a customer to provide solar electricity at guaranteed long-term rates. The developer provides design, financing, maintenance, and support for all elements of the solar electricity system. Some of the major benefits of a PPA to a municipality include:

- very little up-front costs
- Predictable cost of electricity over 15-25 years
- No need to deal with system design and permitting process

- No operating and maintenance responsibilities

As an example, the Drinking Water District in Grafton just completed a 2 Megawatt Solar PV project in the summer of 2013, under a PPA that is anticipated to save the district approximately $150,000 per year for the next 20 year, $3 million in total.

Implementing the solar PV indirectly reduces the greenhouse gas (GHG) emission by generating electricity with an eco-friendly method. When ignited, coal produces about 909 grams of carbon dioxide (CO_2) for each kWh generated while natural gas produces about 465 grams for the same amount of electricity. The proposed 170 kW PV system generates a total clean energy of 210,000 kWh. This means that the facility reduces from 97.64 tons (natural gas) to 190.89 tons (coal) of CO_2 annually after installing the system.
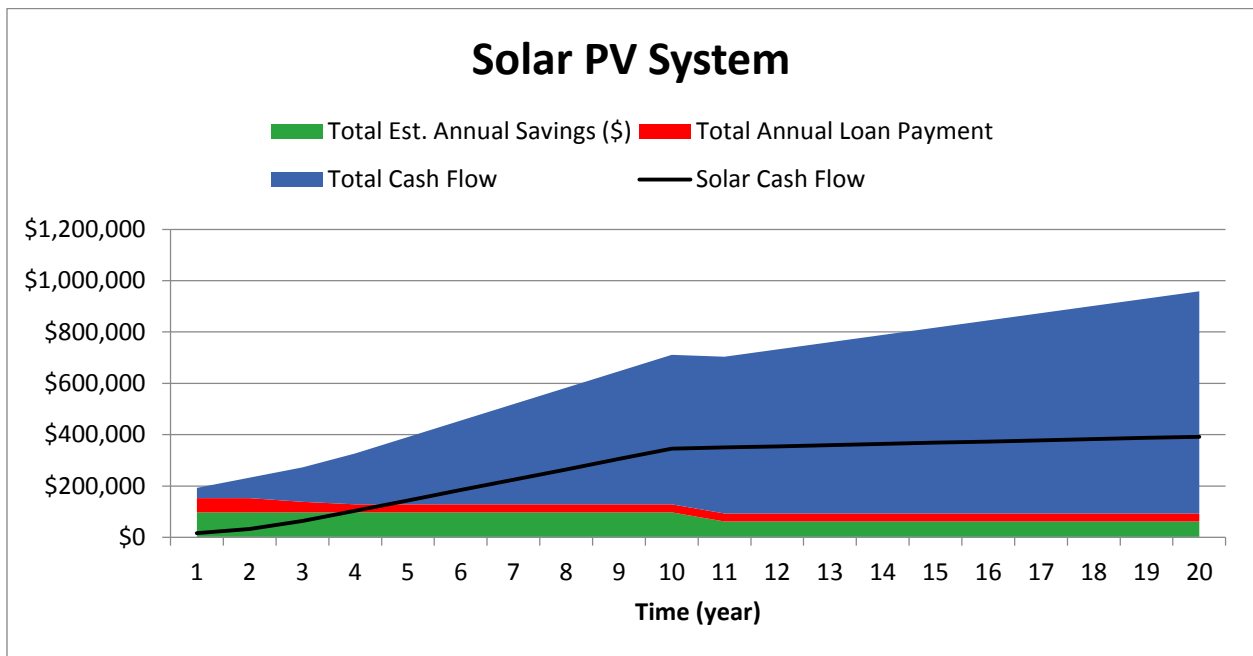
Solar PV System

Figure 15. Solar PV System Cash Flow

4.1.5 – Wind Potential

Wind is another good source of renewable energy that the facility can use to generate electricity. According to the GIS wind map, Massachusetts receives poor to moderate wind in the central region. At 50 m above the ground, the maximum estimated wind speed is 5 m/s at the facility marked with a blue dot in the GIS map in Figure 16, which is equivalent to
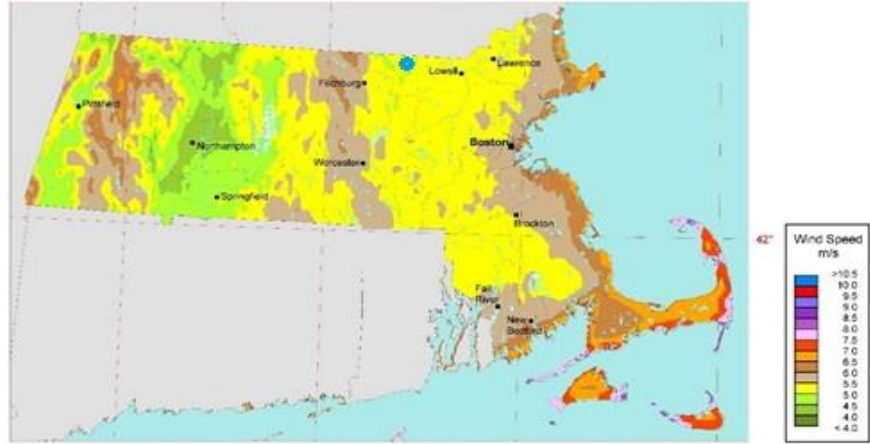
11.18 mph. Wind turbines typically require wind speeds greater than 14.5 mph to become efficient. Typically, wind speeds at higher elevations are used to assess the wind potential. According to Figure 16, the wind speed at 80 m above the ground is around 5.5 m/s, which is 12.3 mph. As such, even at 80 m, the wind speed is still under the efficient level. Total annual energy output (AEO) of a small wind system was calculated using the following formula provided by NREL:

$$\textbf{AEO} = \textbf{0.01328} \times \textbf{rotor diameter(ft)}^2 \times \textbf{average wind speed(mph)}^3$$

Since Pepperell is a small wastewater treatment facility that does not have enough space to install large wind turbines, an option to consider would be to implement a small wind energy system with a maximum energy output of 100 kW. Assuming that a small wind system has an average rotor diameter of 20 m or 65.6 ft, it would be able to produce up to 106,401 kWh/year when built 80 m above the ground. Figure 17 is an energy output curve for 100 kW wind turbine, which gives slightly lower value of around 95,000 kWh.
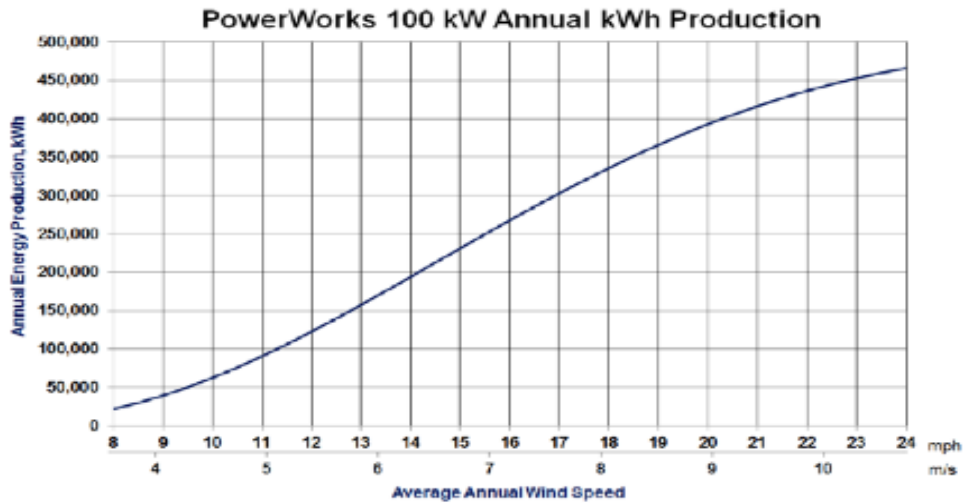
Figure 17. Annual Energy Production of 100 kW Wind Turbine (Powerworks, 2013)

To become energy independent using wind energy, the facility would have to install at least two

100 kW wind turbines. Small wind energy systems are usually for domestic use and they

typically cost around $3,000 to $5,000 per kWh of capacity (Jeandenis, 2010).

Wind turbines require at least 28 to 56 m^2 (300-600 ft^2) of area for construction

(European Wind Energy Association, 2013). They have to be built 30 m above the ground and

below maximum Federal Aviation Administration (FAA) height limit of 137 m (or 450 ft)

(Reichle, 2013). Also, their height has to be at least 9 m taller than any structure within 90 m

radius to get uninterrupted wind. Minimum wind speed of 10 mph at 30 m above the ground is

typically required to spin the blades (European Wind Energy Association, 2013). It is unrealistic

to install a 100 kW wind turbine on the roof because of its size and weight. Therefore, the

options for installing a wind turbine on the ground were considered. The area available for a

wind turbine is shaded with green in Figure 18. The shaded area is 1,823 m^2. Considering that

each 100 kW wind turbines requires a 90 m radius of free space for uninterrupted wind, only one

wind turbine would be able to fit into the space.

Figure 18. Available Area for Wind Turbines (Google Maps, 2014)

The town currently purchases electricity for the facility from National Grid at the

Demand G-2 rate of $0.141/kWh. Since the proposed 100 kW wind turbine is expected to

produce 106,401 kWh annually, the town would save approximately $15,000 per year. If the

engineering and installation fee of the project were to cost 30 percent of the total project cost, the

facility would have to pay an average of $571,430 for implementing a 100 kW wind turbine.

Site assessment grants, feasibility study grants, and development grants are available

through MassCEC Commonwealth wind program. The facility would need a wind turbine with

around a 100 kW power capacity, which falls into the requirements of a small wind and

community wind program. The wind program provides up to $250,000 as a development grant

though the grantee will have to contribute 40 percent of the grant. In other words, the facility

could actually receive up to $150,000 as the grant and the project cost would reduce to $421,430

(MassCEC, 2013). In addition to the initial project costs, the maintenance and operation fees

would have to be considered as well. It is estimated that the maintenance fee each year would be

approximately three to five percent of the project cost, which would mean that a wind turbine

would cost $17,143 to maintain. Since most of the wind turbines have a lifetime of 20 years, it is

reasonable to have 20 years period loan with two percent interest rate to finance the project

(Barnard, 2013). With $0.03/kWh REC rate, a total cumulative cash flow from energy

installation projects would be negative (-) $148,238 as shown in Figure 19. The black line

represents the cash flow of the wind turbine project without taking account of the savings from

the efficiency upgrades. This line gives the total cumulative cash flow of negative (-) $622,118.

Detailed calculations of how the numbers were produced for the cash flow graph for the

economic analysis can be found in Appendix B.
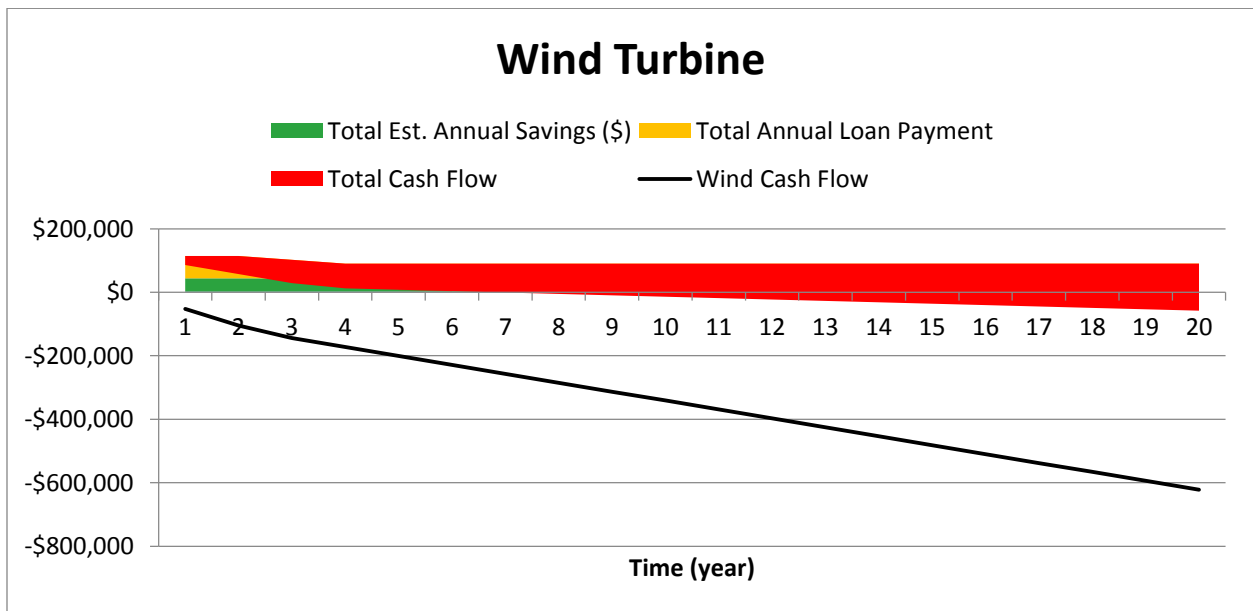
Figure 19. Wind Turbine Cash Flow

As for the hydropower turbine, the wind turbine reduces the amount of the GHG

emission by generating clean energy. The facility is projected to generate 106,410 kWh with the

100 kW wind turbine, which in turn, reduces from about 49.5 tons (natural gas) to 96.73 tons

(carbon) of CO_2 emission.

70

4.1.6 – Hydropower Potential

The Pepperell Wastewater Treatment Facility has a maximum available head of 14.33 m and an average effluent flow rate of 0.52 MGD (0.02278 m^3/s or 21.9 liters/second). Since a reaction turbine requires minimum flow rate of 1 MGD while impulse turbine requires minimum available head of 100 m, they are not feasible to adapt. On the other hand, a pump as turbine (PAT) can operate with water flow rate as low as 10 lps and minimum available head of 10 m. With available head and flow rate, the facility can adapt 1.57 kW PAT system with 75 percent efficiency that can generate 10,314.9 kWh annually (Greacen, 2013). Taking account of Demand G-2 rate of $0.141/kW from National Grid, the facility saves $1,454.40. The project cost of this reaction turbine will be $13,502 given that the turbine cost $8,600/kW on average. The maintenance fee of the hydropower turbine is not counted, for it is minimal due to its small size. Figure 20 shows the cumulative cash flow for 20 years after implement 20 years loan with two percent interest and the annual Renewable Energy Certificate (REC) of $0.025/kWh (Allen, 2013). The total cumulative cash flow is positive for the proposed wind turbine project, for the project cost is relatively high compared to anticipated annual savings of the facility after implementing the turbine.
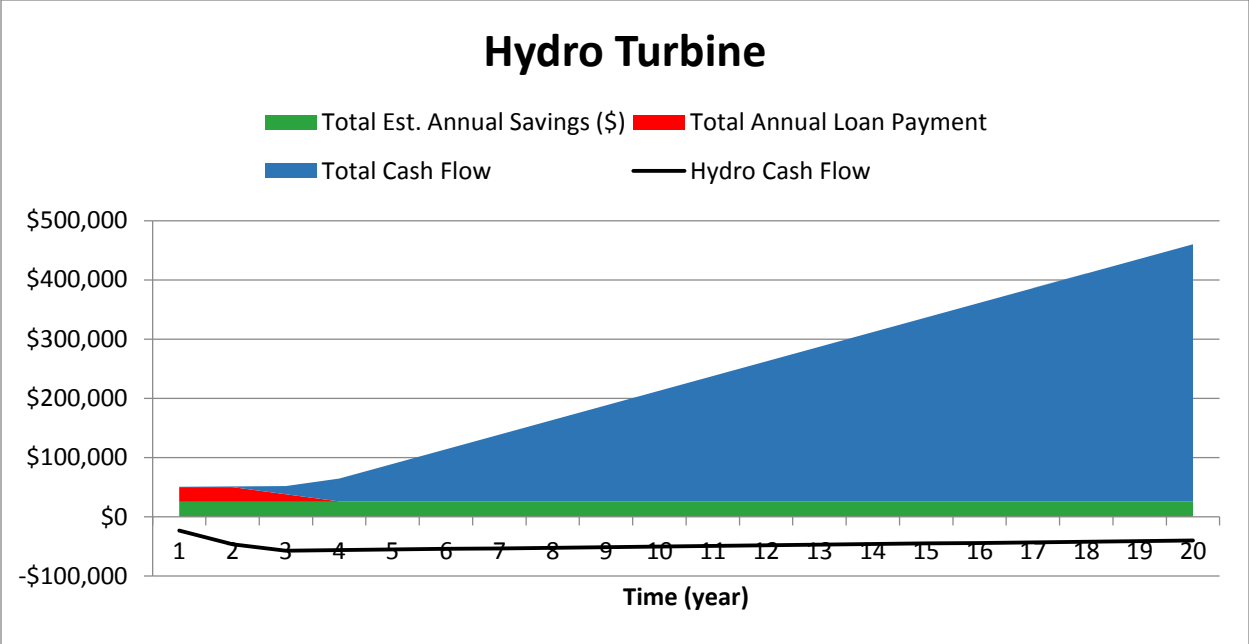
Figure 20. Hydropower turbine Cash Flow

Although the PAT is projected to give a positive cash flow, the facility does not have space for the hydropower turbines. Figure 21 is the effluent channel of the facility and there is barely any space to fit the turbine to generate electricity. Moreover, the flow rate of the effluent stream decreases greatly due to increase in the cross sectional area of the channel.

Figure 21. Effluent Channel

As one of the most clean renewable energy system, the hydropower turbine can indirectly reduce the amount of the GHG emission by replacing fossil fuel based energy generation. Since the turbine produces 10,314.9 kWh annually, the facility reduces from 4.80 tons (natural gas) to 9.37 tons (coal) of CO_2 emission annually.

4.1.7 – Biomass Potential

The Pepperell Wastewater Treatment Facility processes approximately 166 tons (332,000 pounds) of solid wastes every year to produce organic composts. The facility charges $10 per yard of the composts and $15 if delivered. Although producing the composts saves landfill-tipping cost, the facility barely makes profits from selling it due to labor-intensive processes. Hence, it is recommended to consider anaerobic digestion to maximize benefits from the solid wastes by generating thermal and electrical energies.

When anaerobically digested, sewage sludge releases about 120 m^3/ton of biogas that contains 60 to 70 percent methane (Moreno, 2010). Biogas production rate and amount can be greatly increased when the sewage sludge is co-digested with other biodegradable wastes that have high carbohydrate and lipid contents, such
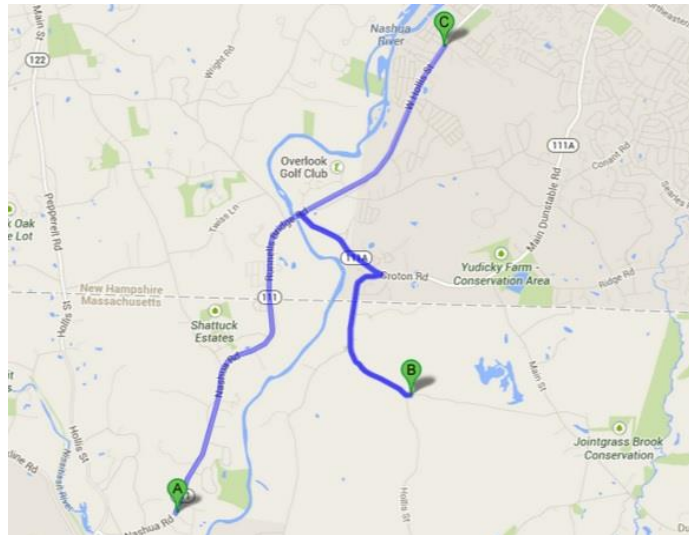
Figure 22. Sources of Organic Wastes (Google Maps, 2014)

as food wastes and dairy wastes. Co-digested wastes produce biogas up to 370 m^3/ton under optimal conditions – high temperature, carbon rich feed stock, and good mixing ratio of sludge and organic wastes, usually 8:2 (Iacovidou, 2012).

73

Figure 22 shows a map marked with letters to indicate different locations. Point A is Pepperell Wastewater Treatment Facility, point B is Four Hills Landfill in Nashua, NH, and point C is Tully Farm Inc. in Dunstable, MA. The distance between point A and B is 5.2 miles, approximately nine minutes by car. The distance between point A and C is five miles, which takes about seven minutes by car. Both sites are easily accessible with trucks and close to one another that they are good sources of biodegradable wastes for co-digestion.

Currently, the Pepperell Wastewater Treatment Facility uses two aerated sludge tanks with a maximum capacity of 109,188 gallons in each tank for storing the sludge before dewatering. Filling and decanting the sludge continues until it thickens and reaches the maximum capacity of the tanks. This process adds an additional six days of storage, increasing the sludge detention time from 15 days to 21 days. Converting the sludge holding tank into an anaerobic digestion (AD) tank will not change the detention time much since the average detention time of mesophilic digester is around 20 days (Alvarez, 2010).

Figure 23. Available Area for Anaerobic Digestion (Google Maps, 2014)

The facility has an available area of 6,374 m^2 including the area currently used for composts as shown in Figure 23. The area shaded with red lines will be the most reasonable place to install the AD system. In most cases, the AD system is cost-effective when the designed wastewater flow rate of the facility is higher than 5 MGD. Although the Pepperell Wastewater Treatment Facility has designed flow of 1 MGD and average flow of 0.5 MGD, conducting a feasibility study is still important, for there are few small facilities that adapted the AD and CHP system even with designed flow of less than 5 MGD. For example, the Fairhaven Wastewater Treatment Facility (average flow rate of 2.7 MGD) installed the AD and CHP system in 2011 and its project cost was around $ 7.2 million. This project was fully covered with the ARRA and MassDEP/SRF Green Infrastructure Reserve grants (Wong, 2011). Based on this, the projected installation cost of the AD and CHP system for the Pepperell Wastewater Treatment Facility is estimated to be around $5 million. MassDEP and MassDOER provide many incentives and services including site assessment, feasibility studies, design assistance, and construction financing assistance. Moreover, MassCEC provides a maximum amount of $400,000 or 25 percent of the total project cost through Commonwealth Organics-To-Energy program to support installing the AD system (EPA, 2013).

Natural gas typically generates electricity at a rate of 11 kWh/m^3 while Biogas with 60 to 70 percent methane produces 7 kWh/m^3, of which only 30 percent is converted to electricity (Jensen, 2010). The rest is lost as heat, which can be recovered with a CHP. The recovered heat is then used for heating the facility buildings and thermophilic digester. If the facility can process the same amount of septage sludge after implementing the AD system, it can produce up to 61,420 m^3 of biogas with co-digestion. This means that the facility can generate 141,880 kWh of electricity and 11,299 therms annually if 100 percent of energy is recovered with the CHP.

Recovery efficiency of the CHP is usually 75 percent, thus the facility actually produces 106,420

kWh and 8,474therms. Converting therms into kWh, the total energy output of the system is

calculated to be 354,708 kWh. Assuming the system is running all year around, the power

capacity of the system is approximately 40.5 kW. A microturbine is the most optimal choice for

the AD system with total capacity smaller than 200 kWh (Cuttica, 2009).

Considering that the facility is buying electricity and natural gas from National Grid at a

rate of $0.141/kWh and $1.337/therm, the facility saves a total of $26,333.55 annually after

implementing the AD and CHP system. Assuming that the project cost for the AD and CHP

system is $4,600,000 with the grant, the total cumulative cash flow from energy installation

projects is negative (-)$3,934,554 with 20 years period loan with two percent interest and

$0.03/kWh REC rate as shown in Figure 24. The negative cumulative cash flow increases even

more without the energy efficiency upgrades as presented in black line in Figure 24. Additional

financial aid may be applied to minimize the negative cash flow. The detailed calculations for the

economic analysis can be found in Appendix B.
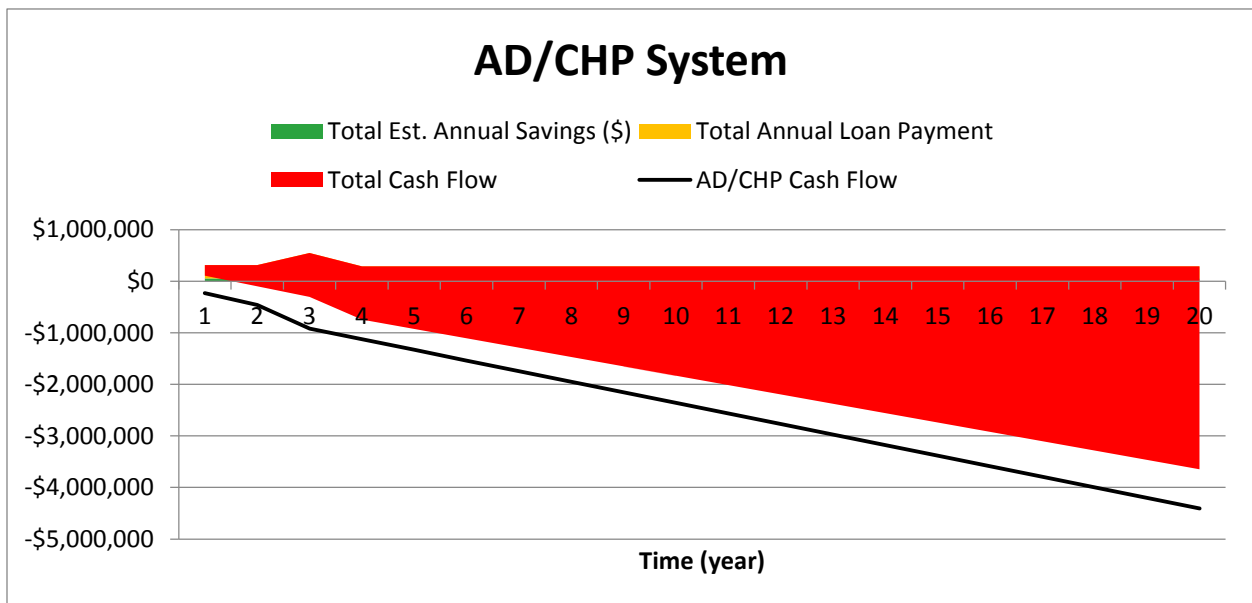
Figure 24. Anaerobic Digestion Cash Flow

The AD and CHP system produces both heat and electricity. Since one therm is equivalent to 29.3 kWh, the facility can produce up to 354,709 kWh with the proposed AD system. This means that the facility reduces from 164.94 tons (natural gas) to 322.43 tons (coal) of CO_2 emission annually.

4.1.8 – Economic Summary

Table 4 shows the economic summary of potential renewable energy options at the Pepperell Wastewater Treatment Facility. The total cash flow in the table below includes the savings from energy efficiency upgrades. Without it, the total cash flow for the renewable energy projects decreases greatly and some becomes negative from positive.

Table 4. The Pepperell WWTP Economic Summary of Renewable Energy Options

Renewable Options	Estimated Project Cost	Incentives	Annual Energy Consumption	Energy Generation	Anticipated Annual Savings	Total Cash Flow
Solar PV	$681,880	$100,000+ REC	210,000 kWh + 8,000therms	210,000 kWh	$29,610 + $23,694	$865,680
Wind Turbine	$571,430	$150,000+ REC	210,000 kWh + 8,000therms	106,401 kWh	$15,000 + $23,694	-$148,238
Hydropower turbine	$13,502	REC	210,000 kWh + 8,000therms	10,315kWh	$1,454.40+ $23,694	$434,061
Anaerobic Digestion	$5,000,000	$400,000+ REC	210,000 kWh + 8,000therms	106,420 kWh 8,474therms	$26,333.55 + $23,694	-$3,934,554

4.1.9 – Environmental Summary

The amount of greenhouse gas that can be reduced depends mostly on how much energy that the renewable power sources can generate. The results in Table 5 show that the use of anaerobic digestion (AD) and solar photovoltaic panels to CO_2 use by the facility would have the greatest impact on the greenhouse gas emission (GHG) emissions.

Table 5. Reduction in the GHG emission (Pepperell)

Estimated reduction in GHG emission		
Renewable options	Coal (tons/yr)	Natural Gas (tons/yr)
Solar PV	190.89	97.64
Wind Turbine	96.73	49.5
Hydropower turbine	9.38	4.80
Anaerobic Digestion	322.43	164.94

4.2 – The Southbridge Wastewater Treatment Facility

The public sanitary sewer and sewage treatment system was first built for the Town of Southbridge in February 21, 1898. The wastewater treatment facility has been expanded due to the growth of the town and the release of the new State and Federal regulations for wastewater discharges and treatment. This facility is a Grade 6 plant with six pump stations and more than 45 miles of sewer line. It maintains composting operations and provides filtered effluent filtration for

Figure 25. Southbridge Wastewater Treatment Facility Satellite View (Google Maps, 2014)

utilization as power plant cooling water. The Southbridge facility is designed to treat 3.77 Million gallons per day (MGD) of wastewater collected from 17,500 residents over the town daily. The actual average of water flow for year 2001 is 2.87 MGD (Southbridge DPW, 2001). The facility is located at 83 Dresser Hill Road, Southbridge, MA 01550. The aerial view of the facility is shown in Figure 25.

4.2.1 – Wastewater Treatment Process

The wastewater first enters the grit chamber to remove the sand grit. Next, the wastewater flows through the primary clarifiers, where the heavy organic material is removed from the wastewater. The heavy organic material or also referred to as sludge is transferred to a sludge holding tank to remove any remaining water. The sludge is then transferred to a compost site where compost is produced from the dewatered sludge and wood chips to be later sold. As for

the clarified water, it goes to the activated bio-filter to degrade the organic material. The treated water enters aeration tanks for further organic material removal and then the final clarifiers clarify the inlet water from the aeration tanks. The next two processes include disinfection by the addition of chlorine and removal of residual chlorine by the addition of sodium bisulfate. The final purified effluent is diffused into Quinebaug River. The treatment process is shown in Figure 26 below.
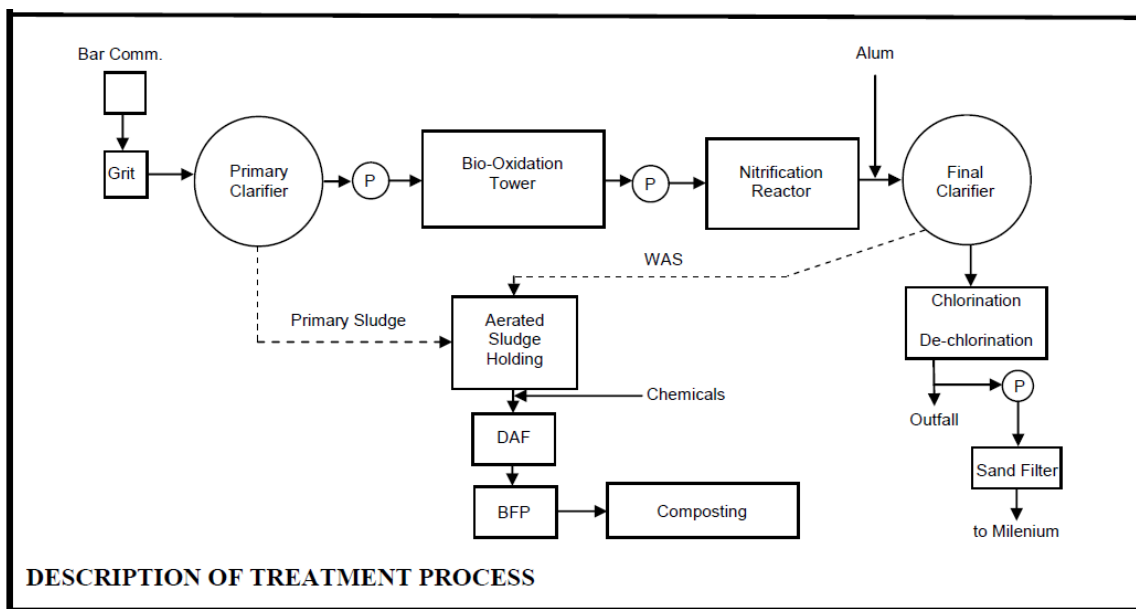
Figure 26. Facility Process Diagram (DiBara, 2013)

4.2.2 – Annual Budget of the Facility

The annual revenue for Southbridge Wastewater Treatment Facility is approximately $3.3 million per year. The electricity expense is about $450,000 per year. Detailed sources of the facility's annual revenue are shown in Figure 27.
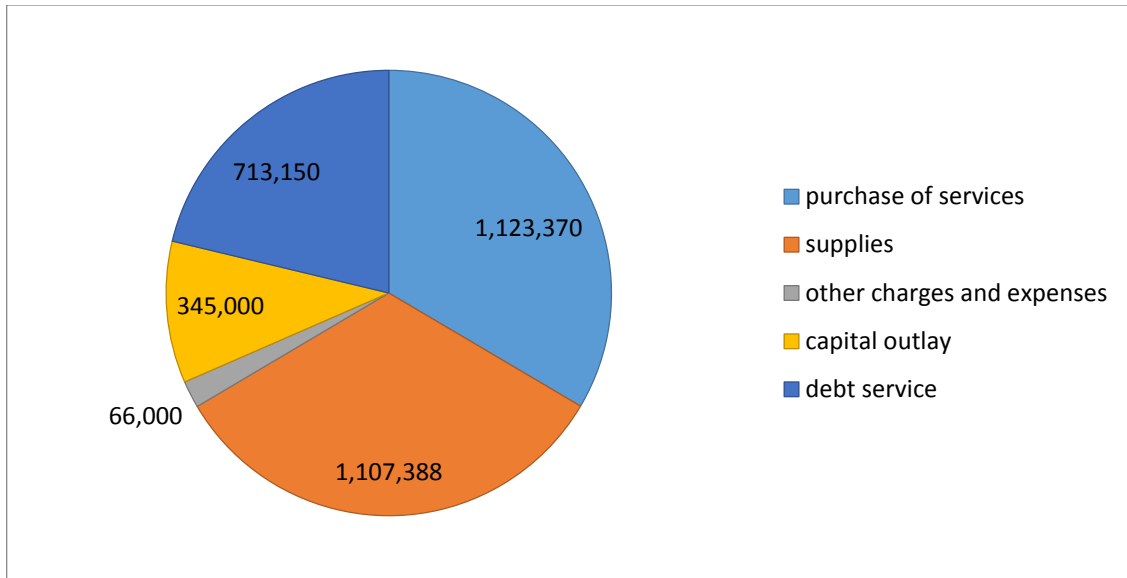
Figure 27. Southbridge Wastewater Treatment Facility Annual Revenue (Southbridge, 2013)
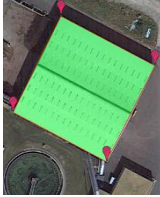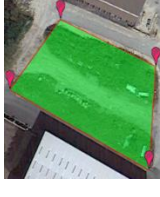
4.2.3 – Energy Efficiency

While this report was being completed, National Grid, Inc. was in the process of completing an energy assessment. As such, this information could not be fully integrated into this report. Implementation of energy efficiency recommendations provided by National Grid will further reduce energy use and costs and make ZNE more attainable for the facility.

4.2.4 – Solar Potential

The Southbridge Wastewater Treatment Facility is located on a property with large open ground area and a number of rooftops that can accommodate solar panels. According to Table 6, the clear shade rooftop area available is calculated to be 4,900 m^2, the available ground area is calculated to be 2,100 m^2, so the total area available for solar system is 7,000 m^2.

Table 6. Solar PV Area Analysis & Estimated Costs of Southbridge (Google Maps, 2014)

Area						total
Estimated Roof Area (m^2)	-	2461.9	1,741.9	-	-	4,900
Estimated Ground Area (m^2)	696.7	-	-	696.7	1,393.5	2,090.3
Estimated area used by solar panels (m^2)	557	1,976	1,393	557	696.75	3,495.15
Estimated Capacity (kW)	111	394	279	111	223	1,118
Estimated Production (kWh)	137,230	484,112	343,200	137,230	274,708	1,377,729
Estimated Costs ($4/watt)	444,000	1,576,000	1,116,000	444,000	892,000	4,472,000

The Town of Southbridge receives about 4 to 4.5 kWh/m^2 of photovoltaic (PV) radiation daily. The maximum amount of electricity that can be generated using this area annually is about 861,203 kWh, with 20% PV efficiency and 75% performance ratio (Fthenakis, 2011). The potential power generation provided by a photovoltaic (PV) system would be about 1,118kW. The average cost would be $4/watt, so the total cost for the system would estimate to be $4,472,000. In the past year, the facility used 2,447,550 kWh of electricity. A solar PV system with a capacity of 1,118 kW could contribute 1,377,729 kWh per year to the operation. Thus after the installation of a solar PV system, the actual electricity usage of the system would be 1,069,821 kWh, resulting in $194,259 annual energy cost savings. The cumulative cash flow

from adapting a solar PV system would be approximately $1 million as shown in Figure 28. Detailed calculation for the economic analysis can be found in Appendix B.
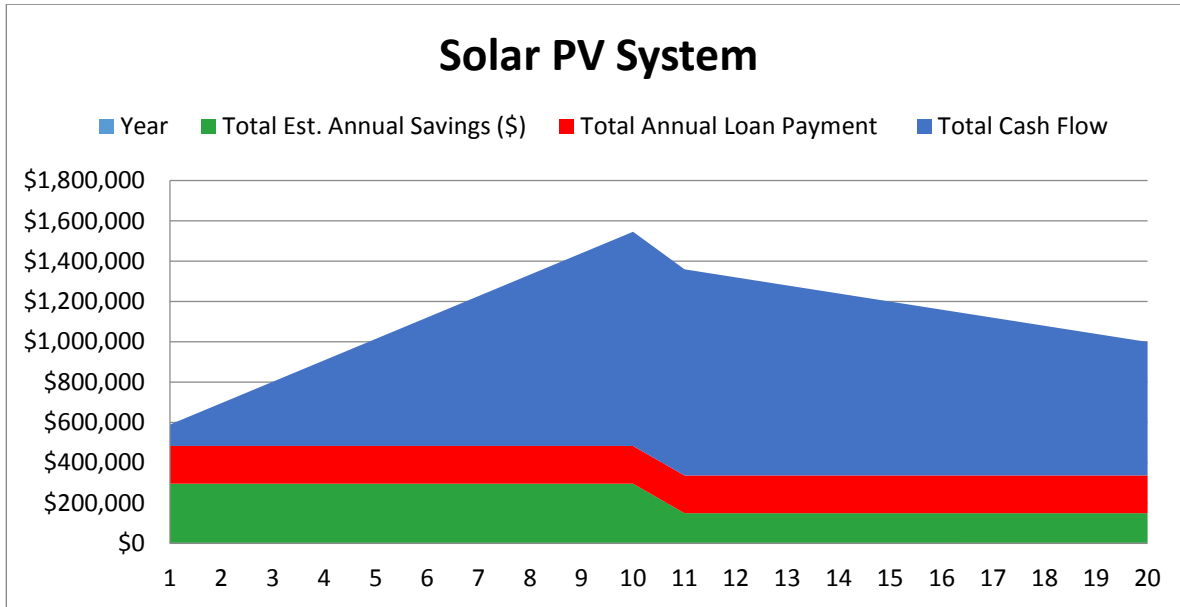
Figure 28. Solar PV System Cash Flow

It is estimated that implementing solar panels could reduce greenhouse gas (GHG) emissions by an amount that is equivalent to 1,252 tons (as coal) and 641 tons (as natural gas).

4.2.5 – Wind Potential

According to Figure 16, the average wind speed in the central Massachusetts at altitude 80 m is only 5 m/s above the ground, which is equivalent to 11.25 mph. Typically, an average annual wind speed minimum of 14.5 mph is desired in order to support the development of a wind project. This wind speed will not be sufficient for efficient turbine operation. Another alternative is to install several small wind turbines with energy output less than 100 kW. The cost for 100 kW wind turbine is about $571,430 including design and construction. The facility will be able to receive up to $150,000 grants from MassCEC for wind turbines with a power rating of 100 kW. However, with this grant, the project cost will reduce to $421,430.

As shown in figure 17, which was shown in earlier sections, the annual energy output at 5 m/s is about 100,000 kWh, thus the annual saving will be $14,100. The facility can get $150,000 incentives and the town contributes $100,000, the remaining $321,430 could be financed from a two percent interest loan. Figure 29 shows the cash flow for wind turbine in the next 20 years. Detailed calculations can be found in the Appendix B.
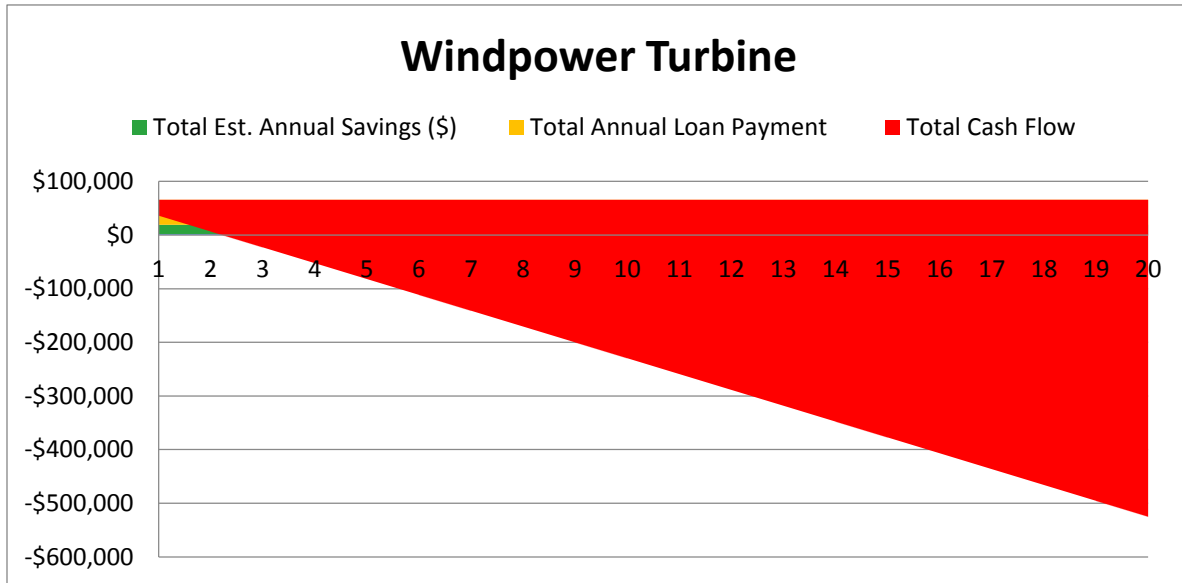
Figure 29. Wind Turbine Cash Flow

Wind turbines reduce the amount of GHG emissions by generating electricity from clean energy. The facility is projected to generate 100,000 kWh with the 100 kW wind turbine, which would reduce emissions in an amount equivalent to that associated with 90.9 tons of CO_2 (coal) and 46.5 tons (natural gas) of CO_2.

4.2.6 – Hydropower Potential

The Southbridge WWTP is currently pumping part of the effluent water to the Millennium Power Plant as cooling water. The discharge from the power plant is pumped back to the Southbridge facility, passing through a conduit down the hill adjacent to the plant by gravity.

Therefore, a hydropower turbine is one option to reduce energy usage for pumping the water to the power plant.

The flow rate for this pipeline varies due to the demand of the Millennium power plant in order to analyze the possible power output from the flow. It was assume the pipeline has a steady flow with a flow rate of 330 gpm and a total available head of 57.9 m from top of the hill to the bottom. The facility cannot meet the minimum requirements for impulse and reaction turbines, but it may be able to adapt a PAT system like that suggested for the Pepperell Wastewater Treatment Facility. The efficiency of the PAT system is usually 75 percent and the capacity factor for hydropower is about 75 percent. The power capacity of this hydro system is calculated to be 4.5kW, and the annual energy generation is 29,484 kWh (Allen, 2013). This calculation is roughly an approximate analysis however and future work done for this proposed project would require further analysis on the process of the flowing water.

The facility buys electricity from National Grid at the rate of $0.141/kWh. After implementing a hydropower turbine, the facility could receive $4,157 from energy savings and $737 from renewable energy certificates every year. The cost for the system installation is about $8,600/kW on average, so the cost for the hydro option in Southbridge WWTP is $38,700, (Allen, 2013). Figure 30 shows the cumulative revenue for the next 20 years. The detailed analysis can be found in Appendix B.
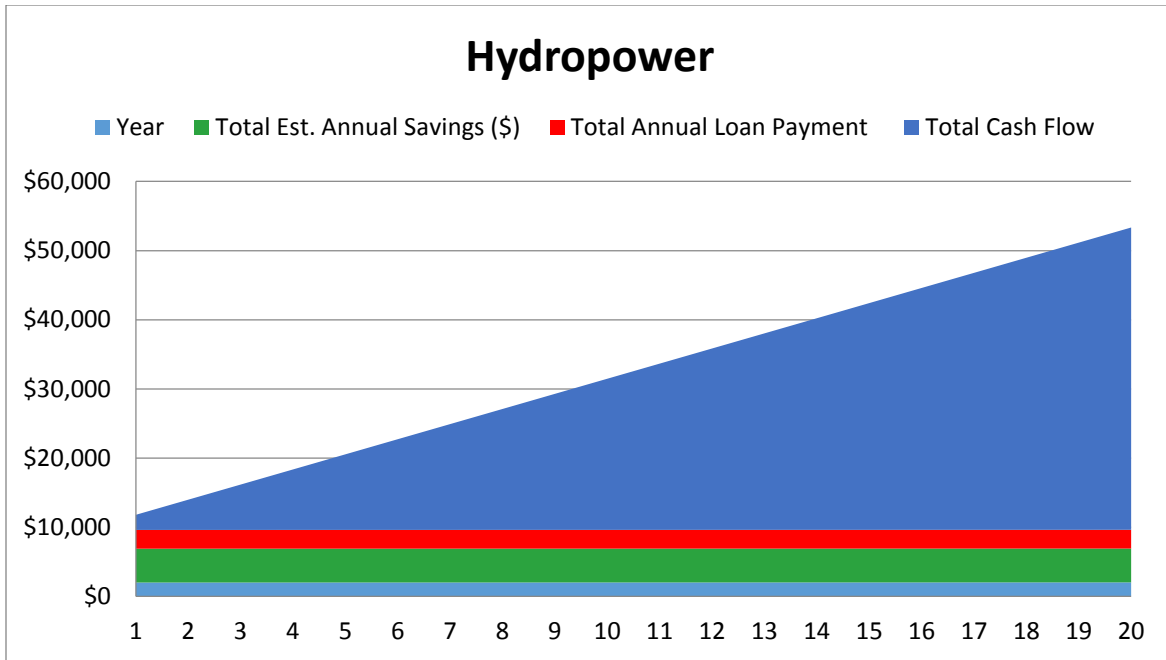
Figure 30. Hydropower Cash Flow

Implementing a hydropower system could directly reduce the greenhouse gas (CHG) emission by using clean energy. It would reduce 26.75 tons (coal) of CO_2 or 13.71 tons (natural gas) of CO_2 if the hydropower turbine project were pursued.

4.2.7 – Biomass Potential

The Southbridge facility is currently selling fertilizer produced from the solid waste that is generated, but the profit from this operation is small. Another way to use the solid waste would be to adapt the anaerobic digester to generate thermal and electrical energy. In 2013, the Southbridge Wastewater Treatment Facility processed 5.88 MG of sludge with an average solids feed of 2.16 percent or 21,549 mg/L. This amount is equivalent to 527.5 dry tons. The sewage sludge releases about 120 m^3/ton of biogas containing up to 70 percent of methane. The amount of biogas that can be produced is about 63,300 m^3/yr (Krasnecky, 2013).

The Fairhaven Wastewater Treatment Facility located in Massachusetts which has an average flow rate of 2.7 MGD, installed the AD and CHP at a cost of $7.2 million. Based on this

case study, the AD and CHP system for Southbridge Wastewater Treatment Facility is estimated to be about $10.32 million. The MassCEC provides $400,000, or 25 percent of the total project cost - whichever is less. Since the energy generation rate of pure methane is 11 kWh/m^3, and the biogas contains 70 percent of methane, the amount of energy that can be generated by the biomass is 487,410 kWh/yr (Jensen, 2010). Most of the energy generated is heat, and only 30 percent of the energy of the biogas can be converted into electricity, so the amount of electricity that can be generated is 109,667 kWh/yr, and the amount of natural gas created is 8,733 therms/year. Applying the Demand G-2 rate, the facility can save $27,139 annually from the AD and CHP system. In addition, the facility can save $14,622/year from REC. Figure 31 shows the cash flow for the AD and CHP system for 20 years after installation. Detailed calculations can be found in the Appendix B.
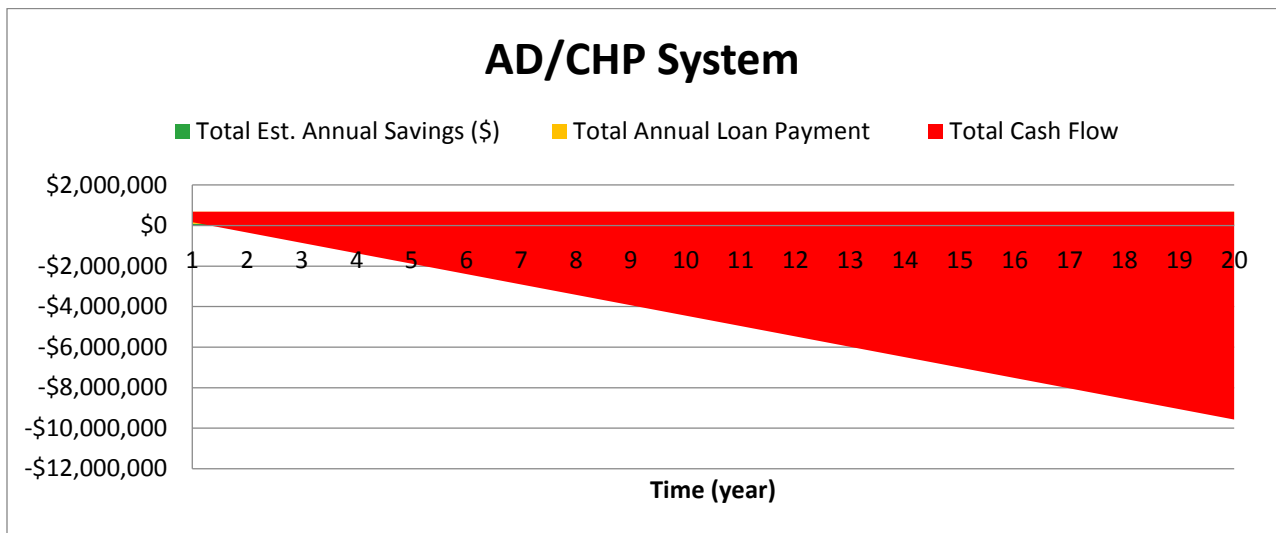
Figure 31. Anaerobic Digestion Cash Flow

Installing the AD system would reduce the GHG emissions indirectly by generating electricity from bio-methane. Natural gas releases 465 grams of CO_2 for every kWh generated while coal produces 909 grams of CO_2 for every kWh. The AD system will reduce CO_2 emission of 216.4 ton annually.

87

4.2.8 – Economic Summary

Table 7 shows the economic summary of potential renewable energy options at the Southbridge Wastewater Treatment Facility. The results show solar PV system is the most cost-effective option for the facility, since it will generate a positive cash flow in the next 20 years. In addition, hydropower is also a good option to adapt, since it cost much less than the other renewable option and can result some profit for the facility.

Table 7. The Southbridge WWTP Economic Summary of Renewable Energy Options

Renewable Options	Estimated Project Cost	Incentives	Annual Energy Consumption	Energy Generation	Anticipated Annual Savings	Total Cash Flow
Solar PV	$4,472,000	$100,000+ REC	2,447,550 kWh	1,377,729 kWh	$194,259	$1,016,190
Wind Turbine	$421,400	$150,000+ REC	2,447,550 kWh	100,000 kWh	$14,100	-$590,860
Hydropower turbine	$38,700	REC	2,447,550 kWh	29,484 kWh	$4,157	$43,702
Anaerobic Digestion	$10 million	$400,000+ REC	2,447,550 kWh	487,410 kWh	$68,724	-$9,923,335

4.2.9 – Environmental Summary

In table 8, the results are somewhat similar between the wind, hydro, and AD alternatives but solar power provides the greatest reduction in greenhouse gas, since the approach is able to produce well over 2 million kWh annually. AD provides the second greatest reduction for greenhouse gas, while the other options have small impacts on the reduction in GHG generation.

Table 8. Reduction in GHG emission (Southbridge)

Estimated reduction in GHG emission		
Renewable options	Coal (tons/yr)	Natural Gas (tons/yr)
Solar PV	1,252	641
Wind Turbine	90.9	46.5
Hydropower turbine	26.75	13.71
Anaerobic Digestion	443	226.6

4.3 – The Millis Water Treatment Facility

The George D'Angelis Water Treatment Facility was constructed in 1998 with several wells and administrative buildings that existed decades prior to that year. Located in Millis, Massachusetts, the municipal facility serves a population of over 8,000 with fresh drinking water throughout the town. In total, there are six well sites and two water storage tanks to help maintain the amount of water being pumped from the wells to be later cleaned and disinfected. On average, approximately 588,000 gallons of water is delivered to over

Figure 32. Aerial View of the Millis DPW Administrative Building & Well 1 (Google Maps, 2014)

2,000 customers daily. The facility processes over 200 million gallons annually.

Figure 33. Aerial view of Well 5 and 6 (Google Maps, 2014)

4.3.1 – Drinking Water Treatment Process

The facility first pumps the water from the wells based on the water level inside the two storage tanks. When the water level inside the storage tanks reach a certain water level, the wells are shut off and are back online until the water level is at a low level. The storage tanks are also used to maintain the water pressure. For wells 1 and 2, the water is sent to the treatment plant where it would be cleaned at the countercurrent air-stripping tower and is then re-pressurized. Sodium hypochlorite and fluoridation are added to the re-pressurized water before being delivered to the distribution system. For wells 3, 4, 5, and 6, the water is cleaned on site at those respective well stations and is then fed directly into the Town's water distribution system.

The average annual expense of the facility for the past three years (2011-2013) is roughly $1.1 million where the average annual revenue is around $1.23 million dollars. Based on the past three years of their budget summary, the water treatment facility each year will earn anywhere from $80,000 to $130,000.
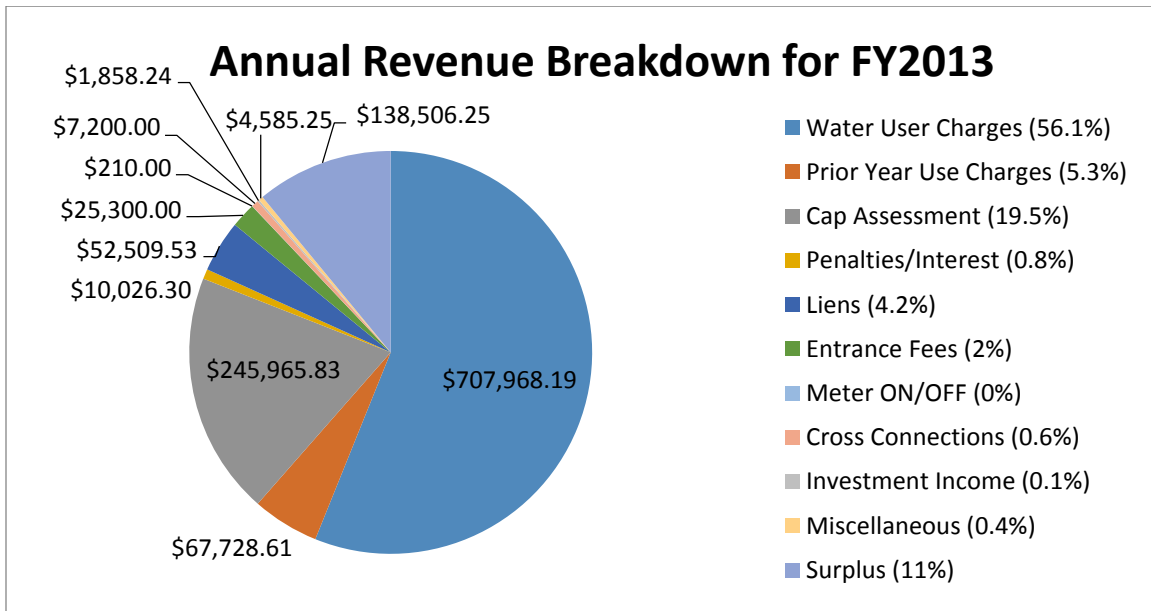
Figure 34. A breakdown analysis of the FY2013 Revenue (Jones, 2012)

In Figure 34, the total revenue for fiscal year 2013 was $1,261,858.20 with more than half of the revenue coming from water usage charges.
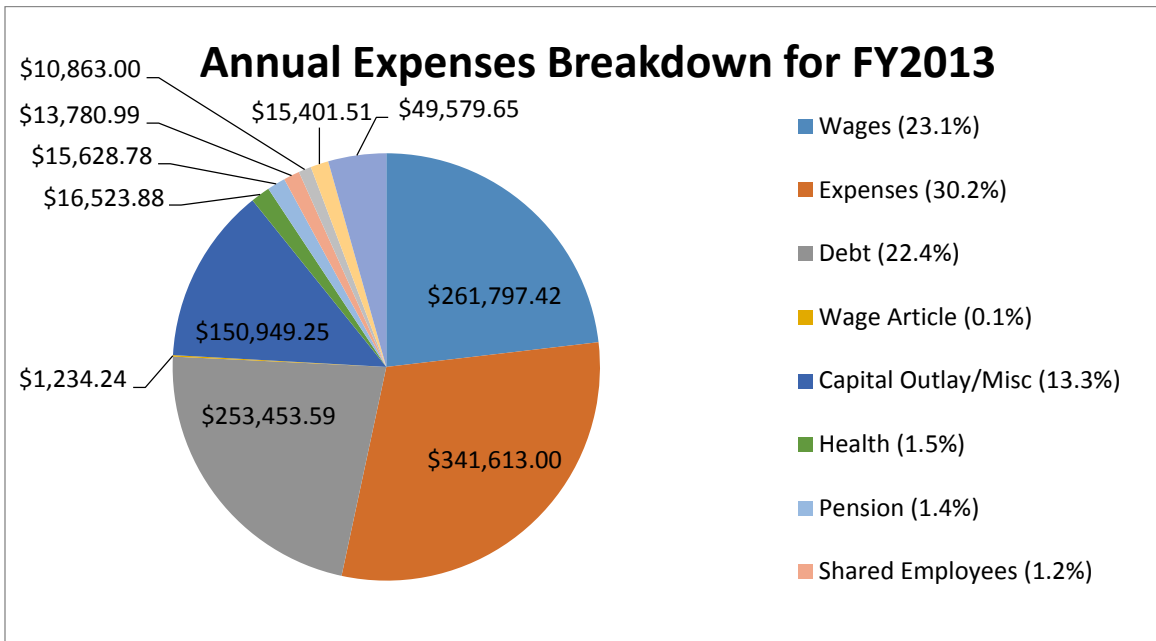
Figure 35. A breakdown analysis of the FY2013 Expenses (Jones, 2012)

In Figure 35, the total cost of operations for the water treatment facility is $1,130,825.30 for fiscal year 2013. The expenses component is responsible for slightly more than 30 percent of the total costs. Almost one third of the expenses ($341,613.00) are due to billing for electricity and fossil fuels used for the facility. For the purpose of this report, reaching zero-net Energy will mean that virtually all costs to pay for outside sources of electricity or fossil fuels will be zero. More information on the costs of electricity will be discussed after a few more pages.

4.3.2 – Current Energy Use of the Facility

As identified by the Energy Facility Audit (September 2012) by The Cadmus Group, Inc., the average power usage during the past two years by the facility was approximately 550 kWh per day. Based on data back in September 2012, the facility annually uses approximately

200,000 kWh of electricity and an estimated 1,930 therms (56,562 kWh). Combining the two

brings the total amount of energy used to be 257,000 kWh (Jones, 2012).

Table 9. Equipment Electric Use at the Facility (Jones, 2012)

	Peak Electricity Use (kW)	Usage Time (avg hr/d)	Daily Electricity Use (kWh/d)
Well #1 pump	13	6.5	83
Well # 2 pump	9	6.5	58
Air stripper blower	12	6.5	77
Re-pressurization pump	34	6.5	218
Exhaust fans	2	12	24
Interior lighting	4	4	16
Exterior lighting	0.15	12	2
Electric heat	18	3	54
Miscellany	1	6.5	7
Total	93		544

The majority of the gas as well as part of the electricity used during the winter are for

heating the facility and keeping the drinking water above the freezing point. Electrical heat was

used at wells 1 and 2. The electricity usage of the facility as shown in Table 9, excluding well 3

to 6, can reach up to 93 kW demand or almost 544 kWh of energy consumed each day (Jones,

2012). With the other wells included, the electricity usage is expected to increase even more.
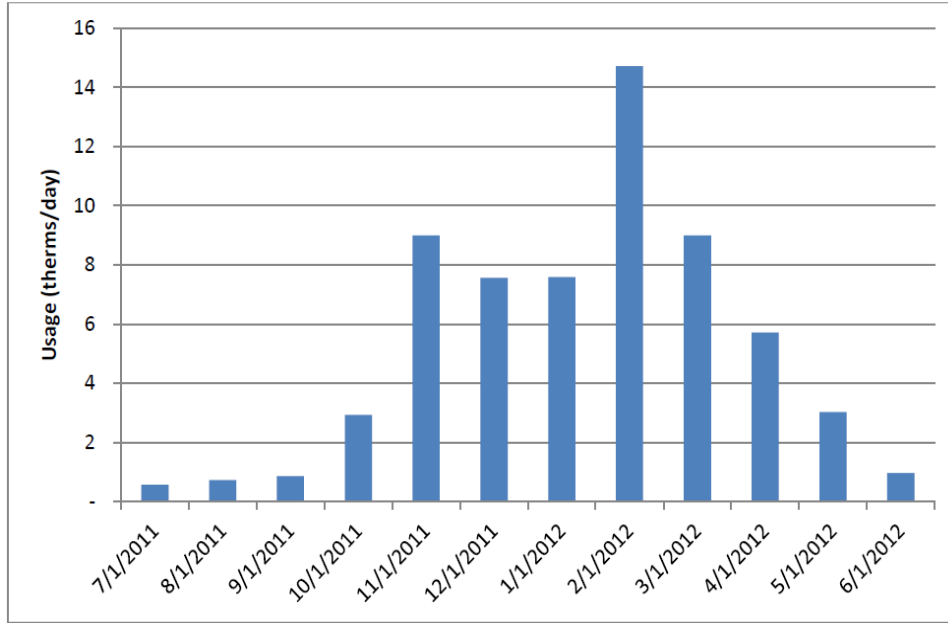
Figure 36. Facility Natural Gas Usage (Jones, 2012)

In Figure 36, the average usage of therms per day is estimated for each month starting

from July 2011 to June 2012. As shown from the graph, most of the usage for natural gas is used

during winter while a minimum is used during the summer. Propane gas used at the facility is not

only used for the heaters but also for the standby 175 kW power generators. The estimated

amount of therms used by the facility was figured out by using this graph, which was 1,930

therms. Propane gas is used to heat the main facility as well

Table 10. Major Electricity Users (Jones, 2012)

as wells 3, 4, 5 and 6.

In Table 10 is more accurate than the previous table as well

as also includes the power usage of both well 4 and well 5.

	Power(kW)
Well #1	12.7
Well #2	8.5
Air stripper	11.2
Re-pressurization pump	34.0
Well #4	41.1
Well #5	32.5

The combined power consumption is approximately 75 kW

but not all wells of the plant will be running so the daily

electricity usage would not be too far off by much as shown

in Table 9.

93

For Figure 37 below, it displays the energy usage of each component below in relations to other components of the facility. The majority of electricity used is needed to power the re-pressurization pump with the well 1 pump and air stripper blower coming in next in terms of amount of electricity used.

The EPA Portfolio Manager Tool was used to benchmark this facility but because this facility is a drinking water treatment plant, the tool is not optimized for these kinds of facilities. In Figure 38, on the next page, the data for FY2008 appears to be a slight anomaly when compared to other years thereafter. Each point on the graph represents each month and how much energy was used that month. Looking at the graph, the drops in energy usage appear to happen in November or December and increases in energy usage right after that. It appears that nearly all of the data for each year hovering around 15 kWh to 17 kWh of energy mark during the majority of the months.
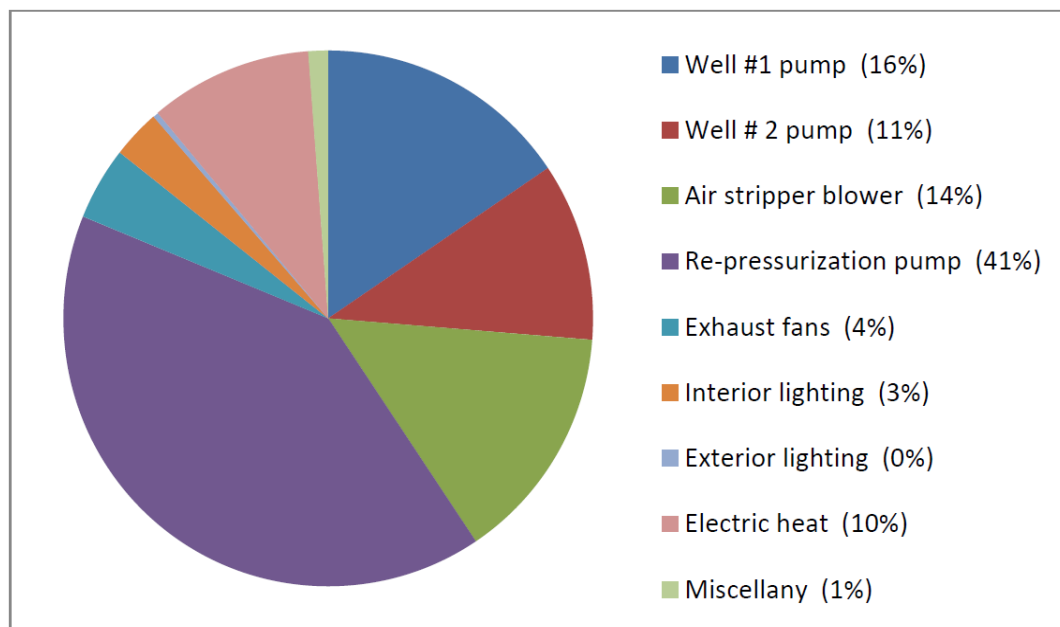
Figure 37. Breakdown of the Facility's Electricity Usage (Jones, 2012)
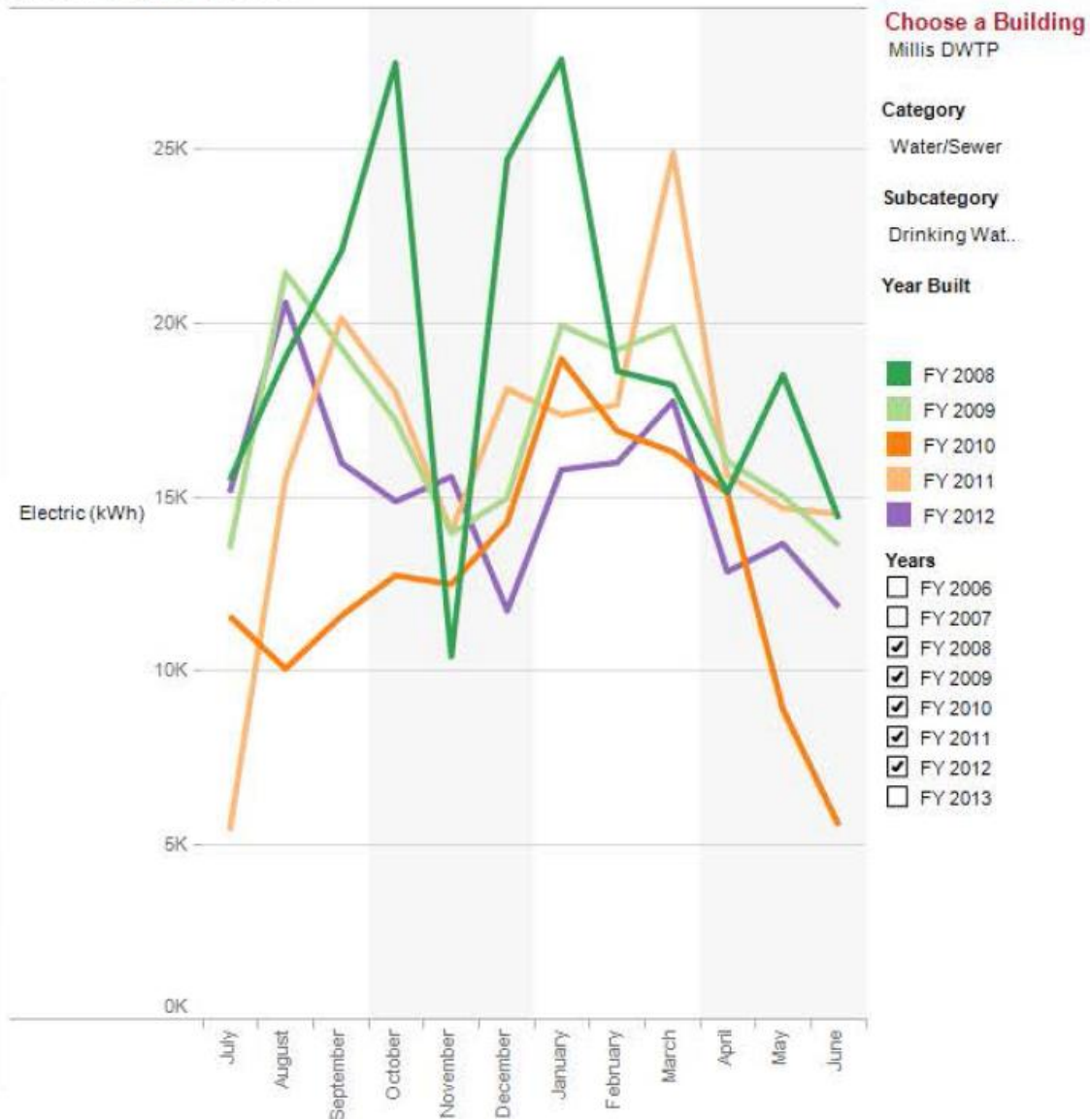
Figure 38. Energy Usage (Electricity Only) Comparison FY2008-FY2012 (Jones, 2012)

    As researched by The Cadmus Group, Inc., the average unit prices that the Millis water

treatment facility purchases electricity is valued at $0.21 per kWh (averaged over the last 6

months ending in June 2012) while propane gas is purchased at $1.20 per therm (propane gas).

The average of the past 12 months ending in June 2012 was $0.17 per kWh. The electricity rate

fluctuates over time where it can be as low as $0.12 to as high as $0.45 per kWh. These values

were last updated in September 2012. As of late 2013, the diesel price was $3.72 per gallon while propane gas was $3 per gallon.

As mentioned earlier, one third of the expenses component of the total costs of the facility is the cost of buying energy. Approximately $110,000 is spent on all energy related expenses for all well pumps and water treatment facilities in Millis. For fiscal year 2013, a total of $106,722.52 was spent for energy (representing almost one third) of the projected $341,612 total expenses component.

The energy costs for 2013 are listed below in table 11. The costs for each section are not limited to the pumping well stations and George D'Angelis Water Treatment Plant but also two other treatment plants including the Paine Water Treatment Plant.

Table 11. Types of Energy Purchased in 2013 (Jones, 2012)

Type of Energy Purchased (FY2013)	Cost ($)
Electricity	$91,013.49
Diesel Fuel	$5,651.53
Propane Gas	$10,057.50
TOTAL PRICE	$106,722.52

The electricity purchased is used to power all the pumps, lighting, and all the wells. For diesel fuel, its purpose was for the generator for well site 1 and 2. For propane gas, its responsibility was to power the generators for well site 3, 5, and 6.

4.3.3 – Efficiency Potential

The Cadmus Group, Inc. conducted energy audits for the George G'Angelis Water Treatment Facility back in September 2012. Below is the summary of recommendations that the group has

recommended to the facility. An organized table of these recommendations can be found in Table 12 on the next page.

- Lower the storage tank levels to the actual required pressure will decrease the pressure on the pumps when they operate. By doing this, the efficiency of the pumps increase as well as the amount of energy is reduced, as less power is needed to lift the water to the pressure for distribution.

- Lower the heating setpoint to reduce costs spent for heating the well buildings. Setting it to a low temperature such as 50 ℉ will be adequate to avoid freezing and reduce energy bills for heating alone.

- Operate most efficient wells preferentially which is Wells 5 and 6 as the first on and last off, and stage Well 4 as the last on and first off. When doing this, this will surely reduce power to lift the water to the pressure for distribution.

- Alternate well pump and re-pressurization pump operation. Cadmus suggests staggering operation such that first the wells and the air stripper run to fill the clearwell, then the well pumps and air-stripper shut off and the re-pressurization pump comes on to pump down the clearwell. The suggested time would be to operate for five to seven minutes at a time, two to three times per hour.

- Operate the Water Treatment Facility during Off-peak hours to reduce demand charges for the electric bill. The billing demand is reduced by 55 percent for off-peak operation. The water facility, including its supply wells (1 and 2) is recommended to operate during off-peak times.

- Clean or replace the pump for Well 4 to increase the efficiency. If the result does not improve the efficiency, then installing a more efficient pump will need to be done.

- Install premium efficiency motors to replace old ones.

- Install energy efficient lighting.

- Replace natural gas furnace with a condensing or pulse-combustion furnace when the natural gas furnaces are near their life cycle.

- Install programmable thermostats or add a heating system monitoring/controlling module to the SCADA system. By doing the SCADA route, there are incentives that may be provided by NSTAR. (Already accomplished)

Table 12. Cadmus Recommendations for Facility (Jones, 2012)

ECM #	Location	Recommended Action	Annual Electric Savings (kWh/yr)	Annual Natural Gas Savings (therm/yr)	Annual Savings ($/yr)	Implementation Cost	Potential Incentives	Net Payback (yr)
Operational Measures								
1	System-wide	Lower storage tank levels	13,833		$2,893	$0	Perhaps*	immediate
2	System-wide	Reduce heating setpoint temperature *	13,686		$2,862	$0	Perhaps*	immediate
Capital Improvement Measures								
3	System-wide	Operate most efficient wells preferentially	10,754		$2,249	$2,500	Perhaps*	1.0
4	George D'Angelis WTF	Alternate well pump and re-pressurization pump operation	0		$8,864	$2,500	Perhaps*	0.3
5	George D'Angelis WTF	Operate Water Treatment Facility During Off-peak Hours	0		$11,018	$2,500	Perhaps	0.2
6	Well #4	Clean or replace well pump #4	27,604		$5,773	$15,808	Perhaps*	2.5
7	Various	Retrofit more efficient motors	4,778		$1,083	$10,556		9.5
8	Various	Retrofit T12 lamps	526		$110	$1,710	$ 450	10.3
9	George D'Angelis WTF	Replace unit heater		255	$282	$2,390	$ 750	5.8
10a	System-wide	Install programmable thermostats **	13,686		$2,862	$3,000		0.9
10b	System-wide	Add heating systems to SCADA	13,686		$2,862	$8,000	$5,400	0.8
Total (Including Interactions)			62,258	255	$28,495	$45,964	$6,600	1.4

* May qualify for re-commissioning or custom incentive if cost-effective.
** Not included in total.

By following their recommendations, the facility can save up to 62,000 kWh and save up to $28,495 where they only need to invest $23,000 with the National Grid incentive which is estimated to be $23,000. Moreover, a 2.5-year term National Grid In-Bill Financing loan with no interest is applied to cover up the project cost. These recommendations are strongly recommended to be pursued as the payback year can be done in less than two years. This will

also definitely mean that less solar panel will need to be installed to cover the rest of the energy that is still being consumed at the facility. James McKay, assistant director of the Millis DPW, stated that the water treatment facility has implemented the temperature transmitters for the SCADA system recommendation after receiving a grant of $22,545 from the 2013 Fall Town Meeting.

In addition to The Cadmus Group's recommendations, the WPI team recommends to replace all of the gas heaters with electric heaters to complement the solar array projects instead of replacing with different gas heaters. This way, the facility will entirely run on electricity and rely solely on solar power except for emergency backup generators when needed. Heaters such as the 7.5 kW electric heaters may cost anywhere from $500 to $1,000 per unit depending on the brand and quality.

4.3.4 – Solar Potential

Of all the renewable energy options out there, solar energy seems to be the best option. After visiting the facilities, the best approach to install solar power generators would be to use photovoltaic ground mounted panels. Roof mounted solar panels would not be a major focus as the DPW garage and the salt shed roofs are restricted to having solar panels be mounted on them.

With the amount of land available to the facility, transfer station, and even the dump, solar energy will provide a huge amount of power, which will have the facility reach zero-net energy. In order for the facility to become zero-net energy, based on 260,000 kWh of annual average usage, it would take about 216 kW of solar PV. To be safe, it would be best to apply 15 percent more in cases where more energy is required in a given year for safety so approximately 300,000 kWh of energy or approximately 250 kW of solar PV.

As mentioned in previous solar analysis section, Massachusetts receives solar insolation of 4 to 4.5 kWh/m^2 per day on average across the state. The maximum energy output that can be generated annually from the available area not including the landfill is 334,330.9 kWh with a 20 percent PV efficiency and 75 percent performance ratio (Fthenakis, 2011). The percentage of land taken up by solar panels, which was roughly 80 percent, was also taken into account.

Roughly, 1055.3 m^2 of solar panel area is needed for solar PV to reach energy independence for the facility. The space needed to support that area is 2638.25 m^2. In Table 13, excluding the dump, the total area available for solar projects is 3,211 m^2. By adding up the total estimated kW and kWh values for those areas only, they would add up to 271.4 kW and 334,330.9 kWh. Comparing this to the energy required of reaching zero-net energy, it would be enough to power the whole facility resulting in savings of $56,836 if assuming the price per kWh is $0.17. The total cost of this project is about $1.086 million where it is $4/Watt to implement the solar arrays at the transfer station, the Water Treatment Facility, and at well station 5 and 6. For the total cost of the project just at the landfill, the pricing would be $3/Watt, resulting in a total of well over $12.4 million.

To help pay for the huge costs, incentives and grants are a possibility. MassDOER provides a total of $100,000 if the facility invests around $100,000 up front. Also, the facility can finance the project through 20 years term loan with two percent interest. The total cumulative cash flow from energy installation projects is $1,338,387 after 20 years shown in Figure 39. A detailed calculation for the economic analysis can be found in Appendix B.
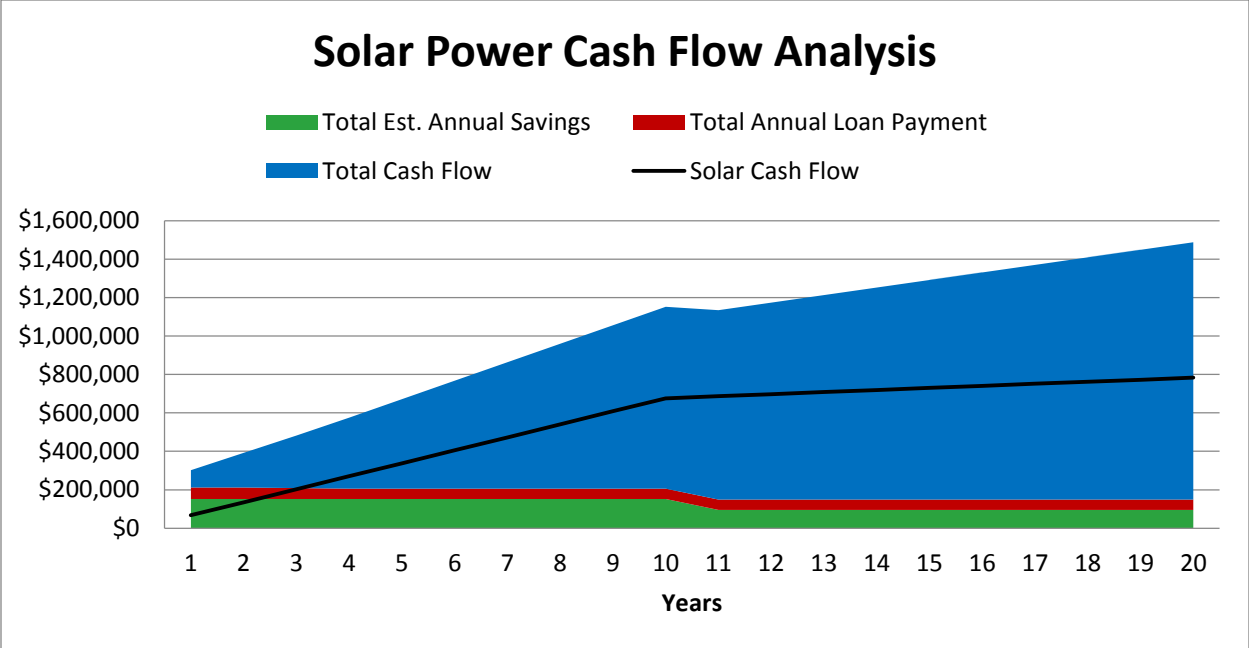
Figure 39. Solar PV System Cash Flow

If the community/town is interested, a solar project can be set up at the town landfill. By doing this, the town can expect approximately 4.36 million kWh, enough to power over 400 homes. However, the cost of implementing this project would be well over $12.4 million at $3 per Watt. To accommodate for parts of the steep areas at the landfill, there are some forms of photovoltaic solar panels that are designed to be installed at landfills with steep slopes. The cost for these kinds of solar panels is generally a bit more expensive and the efficiency is not as great as the non-flexible panels.

As one of the most clean renewable energy options available, solar panels can indirectly reduce the amount of the greenhouse gas emission by replacing fossil fuel based energy generation. The proposed 271.4 kW PV array system generates a total clean energy of 334,330.9 kWh. This means that the facility reduces about 120.9 tons (natural gas) or 236.34 tons (coal) of CO_2 annually after implementing and running the system.

Table 13. Solar PV Area Analysis & Estimated Costs of Millis (Google Maps, 2014)

Area	Water Street	Well #5 & #6	Transfer Station	Town Landfill	TOTALS
Estimated Ground Space (m^2)	~1,023	~630	~1,558	~42,203	~45,414
Estimated Roof Space (m^2)		~110			~110
Estimated Area Used by Solar (m^2)	~409	~320	~623	~16880	~18252
Estimated Capacity (kW)	81.8	65	124.6	3,376	3647.4
Estimated Production (kWh)	100,767.4	80,071.9	153,491.6	4,158,810	4,493,140.9
Estimated Costs ($4 / Watt)	$327,200	$260,000	$498,400	$ 12,476,430 ($3/Watt)	$13,562,030

4.3.5 – Wind Potential

One site in Millis that is owned by the DPW is the landfill, which provides enough space

and is feasible since it is relatively far from the residential zones. The highest point at the

landfill, which is around 48 m above sea level, is barely under the average elevation of the town.

Therefore, wind is not really a viable option, since this wind speed is considered be low for wind

power generation. In Figure 40, Millis (marked by the blue circle crosshairs) appears to be in an

area with lowest class wind power designation, which is denoted in white and has speeds ranging

from 0 to 5.6 m/s. It is estimated that at 50 m, the wind speed would be around 4.5 m/s as those

figures are between the wind speeds for 30 m and 80 m.
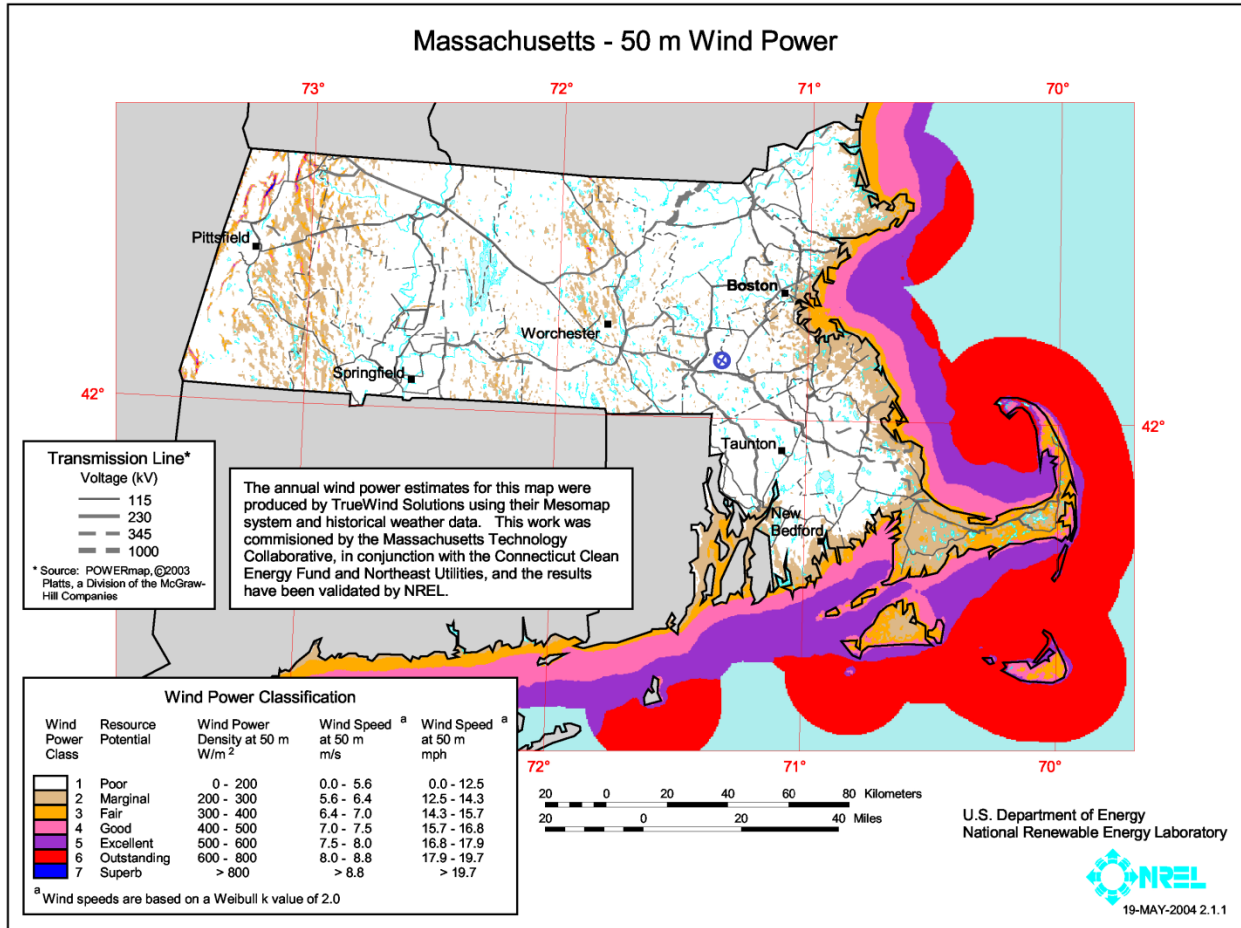
Figure 40. Massachusetts GIS Wind Map at 50 M (NREL, 2013)

At 80 m or even higher, the wind speed makes the project even more feasible but still not adequate to be efficient. According to Table 14, wind speed is estimated to be 5 m/s, which is barely under the recommended minimum speed (NREL, 2013). While a wind turbine can be setup with a height of 80 m, the efficiency rating would still be low as not enough energy is output as well as having a longer payback time.

Table 14. Millis Wind Data Table (NREL, 2013)

Wind Potential Information (update w / Millis data)	
Latitude	42 °10' 56.715"
Longitude	-71 °20' 53.459"
Latitude (NAD83)	42.1824
Longitude (NAD83)	-71.3482
Elevation (m)	48
Estimated Average Wind Speed	
m/s at 30 M	4
m/s at 50 M	4.5
m/s at 80 M	5

Because the wind speed in Millis is relatively slow, it is not feasible to build a small wind turbine such as 100 kW. The annual energy production for 100 kW turbines, as shown in figure 17, generates around 80,000 kWh of energy at 5 m/s wind speed. The energy generated is equivalent of 10 to 11 kW, which is not a lot of power. While the turbine does not output enough power, it can still be used to power some parts of the facility when not running at its peak power. These include well 1, 2, the air stripper blower, and more.

Because the power output is small compared to the power demand for the facility, multiple wind turbines would have to be built to meet the power demand of the facility or even a larger single wind turbine has to be built. The issue with building a bigger wind turbine would generate even more noise and take up more space. For the landfill, at most two wind turbines each with a power capacity of 100 kW can be built where the distance between them is approximately 150 m apart which is almost seven rotor diameters (20 m for each rotor diameter) apart. However, the new studies show that the recommended distance between two wind turbines should be 15 rotor diameters apart (Sandru, 2011). While two wind turbines can be installed at the landfill, it would not be cost efficient according to the study. Even though both wind turbines would not output enough power, the rest of the power produced can be purchased from the power utility company. While the facility will not necessarily reach zero-net energy, the facility

will at least be closer to it than it ever was. Wind turbines could also be built along with solar panels to meet the required power demand and reach zero-net energy possibly. One possible way would be to build one to two wind turbines at the town landfill and a solar array system at the water treatment facility and transfer station area.

The noise generated by the wind turbines would also be unwanted. The distance between residential homes and the hypothetical wind turbine site can vary depending on the law. For Massachusetts, the minimum setback distance is "equal to 3 times the height of the turbine from the nearest existing residential or commercial structure, and 1.5 times the height of the turbine from the nearest property line, other public ways, buildings, critical infrastructure" (DSIRE)

Figure 41. Proposed Wind Turbine Sites
(Google Maps, 2014)

Building a wind turbine near the facility or transfer station does not meet the regulations since it would be too close to a public road or building. The forests surrounding the landfill are lower in elevation compared to the two sites circled in figure 41.

A 100 kW wind turbine where the max tip height can reach up to 60 m can be built at the landfill. Two sites shown on the figure are potential areas where wind turbines can be built. The first wind turbine would be built at site 1 while, if a second wind turbine were considered, then the next recommended spot would be at spot 2 in figure 41.

The cost of building one 100 kW wind turbines would be an average price of

$571,428.57. Please note that this average price is not the usual price of the wind turbine but is

expected to be considered the maximum price for a 100 kW turbine. With grants from the

MassCEC Commonwealth Wind Program, cost of the wind project reduces to $421,428.57

(MassCEC, 2013). The theoretical energy produced annually would reach up to 79,901.5 kWh.

Applying the REC wind rate and electricity purchase rate, the facility saves a total of $42,078.

Also, since most of the wind turbines have a lifetime of 20 to 25 years, it is reasonable to have 20

years period loan with two percent interest rate to finance the project. The total cumulative cash

flow from energy installation projects after 20 years is estimated to be $178,155 as shown in

Figure 42. Detailed calculations for the economic analysis can be found in Appendix B.
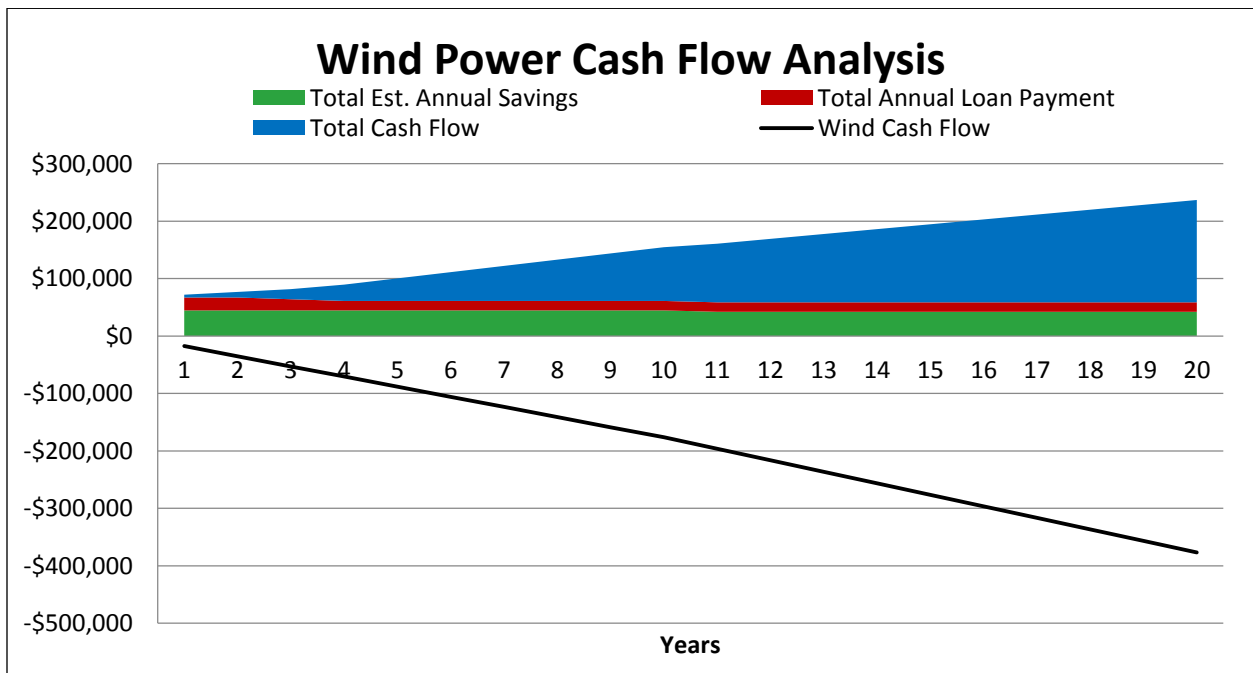
Figure 42. Wind Turbine Cash Flow

Wind turbines produce zero emission and reduce the amount of the GHG emission by

generating clean energy instead. The facility would be projected to generate 79,901.5 kWh with

one 100 kW wind turbine, which in turn, would reduce about 37.15 tons (natural gas) or 72.63 tons (carbon) of CO_2 emission.

4.3.6 – Hydropower Potential

While hydropower is an option of renewable energy for drinking water plants, the requirements needed is having a river with fast moving water or spring water from the mountains. It generates electricity by taking the incoming higher-pressure water and lowers the pressure to match the pressure level for the distribution system through a hydroelectric turbine. For the Millis water treatment facility, having a hydropower would not be feasible because the facility pumps the water upwards from a well and then has to re-pressurize the water before sending it off to the distribution system.

4.3.7 – Biomass Potential

Because this facility is a drinking water facility and not a wastewater facility, the process of implementing anaerobic digesters would be much harder as offsite generation of biomass will be needed. The town landfill is one possibility to install anaerobic digesters due to having biomass and being close to the facility. However, the amount of methane gas generated at that site may not be enough. Currently, the methane gas produced by the landfill is released into the atmosphere according to satellite images.

4.3.8 – Economic Summary

Table 15 shows the economic summary of potential renewable energy options at the Millis Wastewater Treatment Facility. The total cash flow in the table below includes the savings from energy efficiency upgrades. Without it, the total cash flow for the renewable energy projects decreases greatly and some becomes negative from positive.

Table 15. The Millis DWTP Economic Summary of Renewable Energy Options

Renewable Options	Estimated Project Cost	Incentives	Annual Energy Consumption	Energy Generation	Anticipated Annual Savings	Total Cash Flow
Solar PV	$1,085,600	$100,000+ REC	200,000 kWh 1930 Therms	334,331 kWh	$56,836 +$28,495	$1,338,387
Wind Turbine	$571,430	$150,000+ REC	200,000 kWh 1930 Therms	79,902 kWh	$14,100 +$28,495	$155,158

4.3.9 – Environmental Summary

Table 16, it can be seen that the amount of greenhouse gas reduced by solar power is over 200 tons of CO_2 if the solar power replaced the coal power plants or over 120 tons for natural gas power plants. Wind turbine reduces less due to it producing less energy.

Table 16. Reduction in GHG emission (Millis)

Estimated reduction in GHG emission		
Renewable options	Coal (tons/yr)	Natural Gas (tons/yr)
Solar PV	236.4	120.9
Wind Turbine	72.63	37.15

4.4 – Summary of Results

The results indicate that out of all of the investigated facilities, Pepperell and Millis have the potential to achieve zero-net energy whereas Southbridge is able to generate significant energy to cover at least half of its energy demand. The results are summarized as follows.

4.4.1 – Pepperell Wastewater Treatment Facility

The Pepperell Wastewater Treatment Facility, located at 47Nashua Road in Pepperell, has potential for onsite renewable energy generation, including Anaerobic Digestion, Wind, and Solar PV, based on available data. In particular, the cheapest alternative is provided by solar photovoltaic energy, with an estimated potential kW capacity of 170 kW, which could offset an estimated 210,000 kWh each year and bring this facility to Zero-Net Energy. There is space to install both roof and ground mounted solar panels to generate electricity onsite at the Wastewater Treatment Facility.

4.4.2 – The Southbridge Wastewater Treatment Facility

The Southbridge Wastewater Treatment Facility, located at 83 Dresser Hill Road in Southbridge, MA, has potential for reducing its energy costs through efficiency measures and onsite renewable energy generation (Solar PV). In particular, National Grid is currently in the process of conducting an energy audit of the plant, and there is space to install both roof and ground mounted solar panels to generate approximately 1,082,000 kWh per year of electricity onsite (900 kW array system). Since the town has just completed a major capital upgrade of the plant, developing solar photovoltaic energy through a 3rd party developer may be the most cost-effective option to consider.

4.4.3 – The George D'Angelis Water Treatment Facility

The George D'Angelis Water Treatment Facility, located at 7 Water Street in Millis, MA, has the potential for onsite renewable energy generation based on the available data. In particular, the biggest opportunity lies with photovoltaic solar energy, with an estimated potential power capacity of 271 kW, which could offset an estimated 334,000 kWh each year and bring this facility to zero-net energy. There is plentiful of space to install both roof and ground mounted solar panels to generate electricity onsite at the Water Treatment Facility, the Transfer Station, and at the Closed Landfill together.

4.4.4 – Available Financing Options

For municipal and district water and wastewater treatment facilities, there are many sources to receive financial support from. MassDEP, MassDOER, and MassCEC collaborate and provide numerous opportunities, including Commonwealth Organic-To-Energy, Small Wind, Hydro, and Renewable Energy Certificate Programs, to promote reduction in energy consumption and generation of renewable energies at the facility. Furthermore, they are planning another grant opportunity similar to the ARRA, which starts in April 16th, 2014.

In addition to grant opportunities, the facility can finance the project through a low interest, long-term loan provided by the government. The payback year of the loan is usually 20 years and it can be extended for another 10 years depending on the project. Moreover, National Grid provides a zero interest, short-term loan for energy efficiency along with free energy audit service through MassSAVE. More detailed information on loan and grant opportunities for the water and wastewater treatment facilities can be found in Section 2.8 of the report.

5.0 – Conclusions and Recommendations

This project provided an organized method to determine the most cost-effective and energy efficient ways to reach energy independence at three selected facilities. The approach made use of basic guidelines and estimates for quantifying power generation potential for various renewable alternatives, and made use of the financial programs offered by some power utility companies such as National Grid and by the state government. Based on the data collected from virtual site screenings and site visits, the potential energy generation of each type of proposed renewable energy generators was determined and incorporated into the cash flow calculation. After a thorough analysis on the cash flow of the proposed projects in three different sites, conclusions and recommendations could be developed. The approach showed the feasibility of achieving zero-net energy with less financial strain.

The results showed that the facilities in Millis and Pepperell have the potential to reach energy independence through energy efficiency upgrades and implementation of renewable energy generators. Although the results could not confirm that zero net energy could be achieved at the third facility in Southbridge, they did show that this facility could reduce its energy demand significantly. In general, results in these analyses indicated that solar PV systems provided the most cost-effective and feasible renewable energy option for the selected facilities. This, however, does not mean that the solar PV system is the best option among other renewable energy options. In fact, wind turbines, anaerobic digesters, and hydropower turbines have a higher energy output yield, since the efficiency for these systems tends to be substantially greater than the efficiency provided by solar PV systems. The primary reason why these other renewable energy options were found to be impractical at the selected facilities was due to the lower flows and lower amount of biomass generation. In this case, the selected facilities were too small to

111

produce enough biomass to accommodate efficient AD systems and the flows and heads were not high enough to support large hydropower turbines. Moreover, the wind speed in the central Massachusetts was too slow to achieve optimum operational level for the wind turbines that could generate more than 100 kW in power. Nevertheless, it is always important to explore available resources and consider all options when determining the most suitable technologies appropriate for a given site.

Energy efficiency upgrades also provide excellent options for achieving energy independence at water and wastewater treatment facilities. In the Millis Water Treatment Facility and the Pepperell Wastewater Treatment Facility, the anticipated savings from recommended energy efficiency upgrades almost doubled the cumulated cash flow of the solar PV project. In some cases, these savings could transform a project with negative cash flow into one with positive cash flow, making the project more desirable to implement. Hence, the completion of energy audits and the determination of beneficial efficiency upgrades are recommended for maximizing the capital savings at these facilities.

Overall, this project provides a zero-net energy audit report for the three facilities. None of these facilities is obligated to fulfill these recommendations. In fact, the three analyses completed for this project illustrated the approach for assessing the feasibility of achieving zero next energy at water and wastewater treatment facilities. With facility managers using the methodology and recommendations provided in this report, the next steps to take after this report would be to conduct further energy assessments for their facilities and compare these results with this report. Facility operators could hire an energy consultant to confirm the results in the report and prepare in implementing these projects. Facility managers are also strongly encouraged to investigate available grant opportunities to receive financial aid for implementing recommended

projects. To summarize the general approach followed, a guide is included in Appendix A. The guide is divided into several sections to enhance a better understanding of the approach. By completing these analyses and developing this guide, it is hoped that this report general template for future projects aiming to achieve zero-net energy at other water and wastewater treatment facilities.

Appendix

A. Renewable Energy Assessment Guide

This guide is provided to illustrate a basic approach that can be used to assess the feasibility of achieving zero-net energy use at a water or wastewater treatment facility. This approach includes site screening, energy audits, renewable energy assessments, and economic evaluations of the project.

A.1. Site Screening through Google Maps and NREL GIS Maps

Google Maps provides much useful information such as available project area, size of the facility, and surrounding environment and structures. GIS maps, on the other hand, provide information such as solar insolation, wind speed at different altitudes, and biomass production in major cities and towns. This is a very important step since it helps to determine the project location and size that would accommodate with the government regulations regarding construction/installation near the treatment zone (Zone 1). If the project is expected to disturb the treatment process and impact the effluent stream, then the project itself should not be pursued or it should be moved to another location on the site, which is confirmed through site visits.

A.2. Conducting Site Visits

Visiting the sites provide more specific information of the facility that would help the renewable energy assessment. Through site visits, it becomes more certain on the type of renewable resource can be utilized and where to build the renewable energy power generators. This step often opens up new possibilities of generating renewable energy and possibly reaching zero-net energy use at each facility.

A.3. Energy Audits

An energy audit provides data regarding a current energy profile of the facility in detail. Energy consumption and efficiency of every component of the facility are recorded and analyzed to determine energy efficiency upgrades. MassSave, MassDOER, and National Grid offer free audit service for municipal water and wastewater treatment facilities. The energy efficiency upgrades usually lead to a great energy reduction, which will help facilities reach zero-net energy.

A.4. Conducting a Renewable Energy Assessment

Renewable energy assessment depends mainly on three factors, which are amount of renewable resources available, available project area, and budget. Most suitable renewable energy technologies would be selected after a thorough analysis on the data collected from earlier steps. The following sections summaries some basic approaches involved in completing assessments for different types of technologies.

A.4.1. Solar PV Assessment

Capacity of a solar PV system largely depends on the solar insolation at the location, efficiency of the system, and the size of the system. Considering that Massachusetts receives about 4.5 solar hours per day on average and the solar PV system usually has an efficiency of up to 20 percent with a performance ratio of 75 percent, the only flexible variable that decides the capacity of the system is its size. A solar PV system has area efficiency of less than 80 percent meaning that it requires more area than calculated the value to generate the same amount of electricity. The following equation can be used to determine the energy output of the solar PV

system on an annual basis:

$$\textbf{Energy} \left(\frac{\textbf{kWh}}{\textbf{yr}}\right) = \textbf{area} \times \textbf{efficiency} \times \textbf{solar hours} \times \textbf{performance ratio}$$

A typical project cost for a solar PV system is estimated to be around $4,000 per kilowatt. This can be further reduced through several incentives, including 30 percent tax incentives (for private facilities only) and annual Renewable Energy Certificates (REC). Moreover, the facility can finance the project through a low interest, long-term loan provided by the State Revolving Fund (SRF).

A.4.2. Wind Turbine Assessment

A wind turbine requires a large project area and relatively high wind speed to generate electricity as designed. The wind speed at the facility can be determined using the NREL GIS wind map. Wind speed in Massachusetts varies greatly depending on the location (~12 mph in the central region and ~20 mph near the coast). In addition, in Massachusetts, no wind turbines can be built above 450 feet due to a regulation set by Federal Aviation Administration (FAA). This means that the turbine cannot be built at a height greater than 450 feet. Commercially available wind turbines have fixed rotor sizes and tower heights. They also have a fixed power capacity, which requires certain wind speed to operate efficiently. The energy production curves such as Figure 17 are often used to estimate amount of the energy output the wind turbine. Moreover, the equation developed by NREL can be used to verify the value from the energy production curve:

$$\textbf{Output (W} \cdot \textbf{h)} = \textbf{0.01328} \times \textbf{rotor diameter(ft)}^2 \times \textbf{wind speed(mph)}^2$$

A typical project cost for a wind turbine is around $3,000 and $5,000 per kW capacity excluding engineering cost with annual maintenance and repair fee of about three percent of the total

project cost. MassCEC Commonwealth wind program and REC provides incentives for the project costs. The facility can also finance the project through a low interest, long period loan program provided by SRF.

A.4.3. Hydropower turbine Assessment

Three types of in-line micro hydropower turbines that may be applicable are the impulse turbine, reaction turbine, and pump as turbine (PAT). An impulse turbine requires high head loss (~400 m) and relatively slow flow rate (0.5~20 m³/s). It is typically impractical to implement the impulse turbine due to its high head loss requirement. Unlike the impulse turbine, a reaction turbine requires low head loss (~40 m), but a high flow rate (~800 m³/s). If the facility is large and processes a large quantity of influent water daily, then implementation of a reaction turbine is recommended. Otherwise, it is not recommended, for most of the hydropower turbines are custom-built specific to conditions of the facility to maximize the energy efficiency and would cost significantly more than other renewable energy generators. In fact, the project cost of the hydropower turbine is typically at least \$8,600 per kW capacity. Both in-line impulse turbines and reaction turbines require adequate project space in the effluent side of the treatment process, which may be difficult in many facilities, since this can disturb the treatment process. PAT, on the other hand, requires less space, and relatively low flow rates and head (0.01 m³/s and 10 m, respectively). Because of its low requirements, the power capacity for PAT tends to be lower than that of other two turbines. The following equations can be used to estimate the power capacity for an impulse turbine, reaction turbine, and PAT:

$$\textbf{Impulse Turbine}: \textbf{Power (kW)} = \frac{\text{Head (ft)} \times \text{Flow (cfs)}}{11.8} \times \text{efficiency}$$

$$\textbf{Reaction Turbine}: \textbf{Power (kW)} = \frac{1}{2}\text{efficiency} \times \text{density} \times \text{area} \times (\text{volume})^3$$

$$\textbf{PAT}: \textbf{Power} \ (\textbf{W}) = 5 \ \times \ \text{head (meters)} \times \ \text{flow (lps)}$$

The micro hydropower turbines have an average efficiency and power capacity of 75 percent. For a large hydropower turbine system, the project cost could be a couple millions of dollars. To support the facilities that are considering hydropower turbines, MassCEC provides REC and other incentives. In addition, the facility can finance the project with 20 years low interest loan through SRF.

A.4.4 Anaerobic Digestion and CHP Assessment

Wastewater treatment facilities have great potential to generate energy through anaerobic digestion (AD). One ton of sludge can produce about 120 m^3 of biogas, which can be increased to 370 m^3 by adding food waste. About 60 to 70 percent of the biogas consists of methane, which is burned to generate heat and electricity. A combined heat and power system (CHP) is often installed with the AD system to increase energy efficiency and recovery (~75 percent). About 30 percent of the energy it generates is converted into electricity, 60 percent to thermal energy, and the remaining energy is lost via exhaust and radiation. Since the AD and CHP systems are custom built and have extremely high installation costs (at least \$5 million), it is not normally practical to install them for facilities with daily influent flow rates lower than 5 MGD. Following two equations are used to estimate electricity and heat generation for an AD and CHP system.

$$\textbf{Electricity (output)} = \textbf{mass of biomass (ton)} \times \frac{\textbf{370 m}^3}{\textbf{ton}} \times \left(\textbf{0.7} \times \textbf{11} \frac{\textbf{kWh}}{\textbf{m}^3} \right) \times \textbf{0.3} \times \textbf{0.7}$$

$$\textbf{Heat} = \textbf{mass of biomass (ton)} \times \frac{\textbf{370 m}^3}{\textbf{ton}} \times \left(\textbf{0.7} \times \textbf{11} \frac{\textbf{kWh}}{\textbf{m}^3} \right) \times \textbf{0.6} \times \textbf{0.75} \times \frac{\textbf{therm}}{\textbf{29.3kWh}}$$

Another consideration when planning an AD and CHP system is the project area. The AD system requires many components, including anaerobic digesters, gas storage tanks, decanters, and CHP, all to process the sludge. Moreover, the facility has to implement post treatment

processes such as aerobic and chemical stabilization, biological dewatering, and wet separation to meet the discharge standards created by EPA. In fact, the AD and CHP system can only be implemented in a large wastewater treatment facility with a large available project area.

Since the cost and size of the project often cannot be estimated easily, thorough site assessments and planning have to be done to develop the project. Along with REC, MassCEC provides a maximum amount of $400,000 or 25 percent of the total project cost through Commonwealth Organics-To-Energy program to support the facility to adapt the AD and CHP system. Moreover, the facility can apply for SRF to finance the project with a 20-year loan with two percent interest.

A.5. Choosing Renewable Energy Options to Reach Zero-Net Energy Use

After calculating the anticipated energy generation of each renewable energy option, it should be possible to identify the renewable energy options that could lead to zero-net energy use should at the facility. However, due to the high project cost, it may not be possible to implement all options. To determine whether a project is economically viable, it is necessary to analyze project cash flow and calculate potential cumulative savings from the project over a certain period. To determine the total cash flow of a renewable energy option, the amount of grants and incentives and project cost are taken into account as well as financing options such as loans to help payback the costs during a term. The amount of money saved on energy if produced by the renewable energy option is factored in as well as any possible energy efficiency upgrade costs and how much money they could save from that are also factored in. If the cash flow and the savings are positive, the project is feasible. If it is negative, the project has to be either discarded or redesigned to produce a positive cash flow.

B. Project Cost Calculations

B.1. The Pepperell Wastewater Treatment Facility

B.1.1. Solar

Annual solar insolation in Massachusetts is 4.5kWh/m^2 per day. A total area available for the PV system at the facility is 2,196 m^2. Assuming 20% PV efficiency and 75% performance ratio, a maximum amount of energy that can be generated in a given area is calculated as follows:

$$\text{Energy} = \text{area} \times \text{efficiency} \times \text{solar hours} \times \text{performance ratio}$$

$$\text{Energy} = 2{,}196\text{m}^2 \times 0.2 \times (4.5\,\frac{\text{kWh}}{\text{m}^2 \cdot \text{day}} \times \frac{365\text{days}}{\text{yr}}) \times 0.75 = 541{,}039.5\,\frac{\text{kWh}}{\text{yr}}$$

The facility consumes only about 210,000 kWh/yr.

$$210{,}000\,\frac{\text{kWh}}{\text{yr}} = \text{area} \times 0.2 \times \left(4.5\,\frac{\text{kWh}}{\text{m}^2 \cdot \text{day}} \times \frac{365\text{days}}{\text{yr}}\right) \times 0.75$$

$$\text{Area} = 852.3\text{m}^2$$

With area efficiency of 80%, the facility needs 1065.37 m^2.

Size of PV system that generates 210,000 kWh/yr

$$210{,}000\,\frac{\text{kWh}}{\text{yr}} \div 4.5\,\frac{\text{hr}}{\text{day}} \div 365\,\frac{\text{day}}{\text{yr}} \div 0.75 = 170.47\text{kW}$$

Since an average PV system costs $4,000/kW, the total project cost is $681,880.

B.1.2. Wind

According to GIS wind map, the wind speed at the facility is 12.3 mph at 80 m above the ground. For an average 100 kW wind turbine with 20 m (65.617ft) rotor diameter, the annual energy output (AEO) can be calculated as below (**note**: since the power output equation for the hydropower turbine requires units in feet, all the numbers are converted from meters to feet.).

$$\text{AEO} = 0.01328 \times \text{rotor diameter(ft)}^2 \times \text{average wind speed(mph)}^3$$

$$\text{AEO} = 0.01328 \times (65.617\text{ft})^2 \times (12.3\text{ mph})^3 = 106{,}401.1\,\frac{\text{kWh}}{\text{yr}}$$

$$\text{Anticipated annaul saving: } 106{,}401.1\,\frac{\text{kWh}}{\text{yr}} \times \frac{\$0.141}{\text{kWh}} = \frac{\$15{,}002.55}{\text{yr}}$$

Since a wind turbine costs from $3,000/kW to $5,000/kW, a 100 kW unit costs around $300,000 to $500,000. With an additional 30% engineering and installation costs, the facility has to pay an average of $517,428.57

$$\text{Total project cost}(x) = \$300,000 + 0.3x \text{ and } \$500,000 + 0.3x$$

$$x = \frac{\$300,000}{0.7} = \$428,571.43$$

$$x = \frac{\$500,000}{0.7} = \$714,285.71$$

$$\text{Average project cost} = \frac{\$428,571.43 + \$714,285.71}{2} = 571,428.57$$

B.1.3. Hydro

The average flow rate is 21.9lps, and the head is 14.3 m. Assume the efficiency of the turbine is 75%, and the generate factor is 75%. The size of the system can be calculated as follows:

$$5 \times 21.91\text{lps} \times 14.3 \text{ m} = 1,569.85\text{W} \sim 1.57\text{kW}$$

The annual power output of the system:

$$1.57\text{kW} \times \frac{24\text{hr}}{\text{day}} \times \frac{365\text{days}}{\text{yr}} \times 75\% = \frac{10,314.9\text{kWh}}{\text{yr}}$$

$$\text{Anticipated annual savings:} \frac{10,314.9\text{kWh}}{\text{yr}} \times \frac{\$0.141}{\text{kWh}} = \frac{\$1,454.40}{\text{yr}}$$

$$\text{Cost of the system:} 1.57\text{kW} \times \frac{\$8,600}{\text{kW}} = \$13,502$$

B.1.4. Biomass

Amount of the sludge produced annually: 332,000 lbs = 166 tons

Biogas production rate of the sludge when anaerobically digested: 120 m³/ton

$$\text{Amount of biogas produced:} \frac{166\text{tons}}{\text{yr}} \times \frac{120\text{m}^3}{\text{ton}} = 19,920 \frac{\text{m}^3}{\text{yr}}$$

Energy generation rate of pure methane: 11 kWh/m³

Amount of energy generated with biogas (70% methane):

$$19,920 \frac{\text{m}^3}{\text{yr}} \times \left(0.7 \times 11 \frac{\text{kWh}}{\text{m}^3}\right) = 153,384 \frac{\text{kWh}}{\text{yr}}$$

Considering that, CHP has an average efficiency of 75% and only 30% of the total energy produced can be converted into electricity,

$$0.3 \times 153{,}384 \frac{\text{kWh}}{\text{yr}} \times 0.75 = 34{,}511.4 \frac{\text{kWh}}{\text{yr}}$$

$$0.7 \times 153{,}384 \frac{\text{kWh}}{\text{yr}} \times 0.75 \times \frac{1 \text{therm}}{29.3 \text{ kWh}} = 2{,}748.4 \frac{\text{therms}}{\text{yr}}$$

The facility buys electricity and natural gas from National Grid at the rate of \$0.141/kWh and \$1.337/therms, respectively.

Anticipated annual savings:

$$\left(34{,}511.4 \frac{\text{kWh}}{\text{yr}} \times \frac{\$0.141}{\text{kWh}}\right) + \left(2{,}748.4 \frac{\text{therms}}{\text{yr}} \times \frac{\$1.337}{\text{therms}}\right) = \frac{\$8{,}540.72}{\text{yr}}$$

Biogas production rate of the sludge when anaerobically co-digested: 370 m³/ton

$$\text{Amount of biogas produced:} \frac{166 \text{tons}}{\text{yr}} \times \frac{370 \text{m}^3}{\text{ton}} = 61{,}420 \frac{\text{m}^3}{\text{yr}}$$

Amount of electricity generated:

$$61{,}420 \frac{\text{m}^3}{\text{yr}} \times \left(0.7 \times 11 \frac{\text{kWh}}{\text{m}^3}\right) \times 0.3 \times 0.75 = 106{,}410 \frac{\text{kWh}}{\text{yr}}$$

Amount of heat generated and recovered:

$$61{,}420 \frac{\text{m}^3}{\text{yr}} \times \left(0.7 \times 11 \frac{\text{kWh}}{\text{m}^3}\right) \times 0.7 \times 0.75 \times \frac{1 \text{therm}}{29.3 \text{ kWh}} = 8{,}474 \text{therms}$$

Anticipated annual savings:

$$\left(106{,}410 \frac{\text{kWh}}{\text{yr}} \times \frac{\$0.141}{\text{kWh}}\right) + \left(8{,}474 \frac{\text{therms}}{\text{yr}} \times \frac{\$1.337}{\text{therms}}\right) = \frac{\$26{,}333.55}{\text{yr}}$$

CHP size:

$$\frac{106{,}410 \text{ kWh}}{\text{yr}} + \left(\frac{8{,}474 \text{therms}}{\text{yr}} \times \frac{29.3 \text{ kWh}}{\text{therm}}\right) = \frac{354708.2 \text{ kWh}}{\text{yr}}$$

$$\frac{354708.2 \text{ kWh}}{\text{yr}} \times \frac{1 \text{day}}{24 \text{hr}} \times \frac{1 \text{yr}}{365 \text{day}} = 40.49 \text{kW}$$

B.2. The Southbridge Wastewater Treatment Facility

B.2.1. Solar

Annual solar insolation in central Massachusetts is about 4.5kWh/m² per day. The total area available for the PV system is about 6,592 m².

The amount of electricity can be generated

$$\text{Electricity} = 6{,}592 \text{ m}^2 \times 0.2 \times \left(4.5 \frac{\text{kWh}}{\text{m}^2 \cdot \text{day}} \times \frac{365 \text{days}}{\text{yr}}\right) \times 0.75 = 1{,}377{,}729 \frac{\text{kWh}}{\text{yr}}$$

Size of the PV system

$$1{,}377{,}729 \frac{\text{kWh}}{\text{yr}} \div 4.5 \frac{\text{hr}}{\text{day}} \div 365 \frac{\text{day}}{\text{yr}} \div 0.75 = 1{,}118\text{kW}$$

Since an average PV system costs \$4,000/kW, the total project cost is \$4,472,000.

B.2.2. Wind

The amount of electricity can be generated annually is 200,000 kWh. The cost is \$644,250 with engineering and installation cost.

Anticipated annual saving:

$$100{,}000 \frac{\text{kWh}}{\text{yr}} \times \frac{\$0.141}{\text{kWh}} = \frac{\$14{,}100}{\text{yr}}$$

Class I REC (yr 1-20): \$0.03/kWh $\times$ 100,000 $\frac{\text{kWh}}{\text{yr}}$ = \$3,000

B.2.3. Hydro

The average flow rate is 20.8 liter per second, and the head is 57.9 meter. Assume the efficiency of the turbine is 75%, and the generate factor is 75%. The size of the system can be calculated as

$$\text{Power (W)} = 5 \times 0.75 \times 57.9 \times (\text{meters}) \times 20.8 \left(\frac{\text{liters}}{\text{sec}}\right) = 4.5\text{kW}$$

The annual power output = 4.5kW $\times$ 24h $\times$ 365day $\times$ 75% = 28,484 kWh

The cost of the system is \$38,700.

B.2.4. Biomass

Amount of sludge produced annually: 527.5 dry ton

Biogas production rate of the sludge when anaerobically digested: 120 m³/ton

$$\text{Amount of biogas produced:} \frac{527.5 \text{tons}}{\text{yr}} \times \frac{120 \text{m}^3}{\text{ton}} = 63{,}300 \frac{\text{m}^3}{\text{yr}}$$

Energy generation rate of pure methane: 11 kWh/m³

Amount of energy generated with biogas (70% methane):

$$63{,}300 \frac{\text{m}^3}{\text{yr}} \times \left(0.7 \times 11 \frac{\text{kWh}}{\text{m}^3}\right) = 487{,}410 \frac{\text{kWh}}{\text{yr}}$$

Considering that CHP has an average efficiency of 75% and only 30% of the total energy produced can be converted into electricity,

$$0.3 \times 487{,}410 \frac{\text{kWh}}{\text{yr}} \times 0.75 = 109{,}667.25 \frac{\text{kWh}}{\text{yr}}$$

$$0.7 \times 487{,}410 \frac{\text{kWh}}{\text{yr}} \times 0.75 \times \frac{1\,\text{therm}}{29.3\ \text{kWh}} = 8{,}685 \frac{\text{therms}}{\text{yr}}$$

Anticipated annual savings:

$$\left(109{,}667 \frac{\text{kWh}}{\text{yr}} \times \frac{\$0.141}{\text{kWh}}\right) + \left(8{,}685 \frac{\text{therms}}{\text{yr}} \times \frac{\$1.337}{\text{therms}}\right) = \frac{\$27{,}074}{\text{yr}}$$

B.3. The Millis Water Treatment Facility

B.3.1. Solar Power

Annual solar insolation in Massachusetts is 4.5kWh/m^2 per day.

The average PV system costs $4,000/kW.

The facility consumes a combined energy total of 260,000 kWh/year.

$$260{,}000 \frac{\text{kWh}}{\text{year}} = \text{area} \times 0.2 \times \left(4.5 \frac{\text{kWh}}{\text{m}^2 \cdot \text{day}} \times \frac{365\,\text{days}}{\text{year}}\right) \times 0.75$$

$$\text{Area} = 1055.3\ \text{m}^2$$

$$260{,}000 \frac{\text{kWh}}{\text{year}} \div 4.5 \frac{\text{hours}}{\text{day}} \div 365 \frac{\text{day}}{\text{year}} \div 0.75 = 211.06\ \text{kW}$$

The power output of the solar array system where it produces 260,000 kWh of energy is estimated to be 211.06 kW.

The cost of this PV solar array would be $844,240.

A total area available for the PV system at the facility along (not including transfer station or landfill) is about 1,763 m^2. The estimated energy generated and power capacity of each solar project is shown below:

$$\text{Energy (kWh)} = \text{area (m}^2) \times \text{efficiency} \times \text{solar insolation } \left(\frac{\text{kWh}}{\text{m}^2}\right) \times \text{performance ratio}$$

where area is the total area of the solar panels. Only 40% of the land is actually used by solar panels.

$$\text{area (m}^2) = \text{available land or roof area (m}^2) \times 40\%$$

The Water Treatment Facility Area (including Well 5/6 Area)

$$\text{area} = 1{,}763\ \text{m}^2 \times 40\% = 729\ \text{m}^2$$

$$\text{Energy} = 729 \text{ m}^2 \times 0.2 \times (4.5 \frac{\text{kWh}}{\text{m}^2 \cdot \text{day}} \times \frac{365 \text{days}}{\text{year}}) \times 0.75 = 180{,}839.3 \frac{\text{kWh}}{\text{year}}$$

$$180{,}839.3 \frac{\text{kWh}}{\text{year}} \div 4.5 \frac{\text{hours}}{\text{day}} \div 365 \frac{\text{day}}{\text{year}} \div 0.75 = 146.8 \text{ kW}$$

The cost of this PV solar array would be $587,200.

The Transfer Station Area

$$\text{area} = 1{,}558 \text{ m}^2 \times 40\% = 623 \text{ m}^2$$

$$\text{Energy} = 623 \text{ m}^2 \times 0.2 \times (4.5 \frac{\text{kWh}}{\text{m}^2 \cdot \text{day}} \times \frac{365 \text{days}}{\text{year}}) \times 0.75 = 153{,}491.6 \frac{\text{kWh}}{\text{year}}$$

$$153{,}491.6 \frac{\text{kWh}}{\text{year}} \div 4.5 \frac{\text{hours}}{\text{day}} \div 365 \frac{\text{day}}{\text{year}} \div 0.75 = 124.6 \text{ kW}$$

The cost of this PV solar array would be $498,400.

The Town Landfill Area

$$\text{area} = 42{,}203 \text{ m}^2 \times 40\% = 16{,}880 \text{ m}^2$$

$$\text{Energy} = 16{,}880 \text{ m}^2 \times 0.2 \times (4.5 \frac{\text{kWh}}{\text{m}^2 \cdot \text{day}} \times \frac{365 \text{days}}{\text{year}}) \times 0.75 = 4{,}158{,}810 \frac{\text{kWh}}{\text{year}}$$

$$4{,}158{,}810 \frac{\text{kWh}}{\text{year}} \div 4.5 \frac{\text{hours}}{\text{day}} \div 365 \frac{\text{day}}{\text{year}} \div 0.75 = 3{,}376 \text{ kW}$$

For larger systems, it would be $3,000/kW. The cost of this PV solar array would be $12,476,430.

B.3.2. Wind Power

According to GIS wind map, the wind speed at the facility is 5 m/s (11.18 mph) at 50 m above the ground. For an average 100 kW wind turbine with 20 m (65.617ft) rotor diameter, the height of the turbine can range from 25 to 60 m.

The annual energy output (AEO) can be calculated as below.

$$\text{AEO} = 0.01328 \times \text{rotor diameter (ft)}^2 \times \text{average wind speed (mph)}^3$$

$$\text{AEO} = 0.01328 \times (65.617 \text{ ft})^2 \times (11.18 \text{ mph})^3 = 79{,}901.7 \frac{\text{kWh}}{\text{year}}$$

$$\text{Anticipated annual savings: } 79{,}901.7 \frac{\text{kWh}}{\text{year}} \times \frac{\$0.17}{\text{kWh}} = \frac{\$13{,}583.29}{\text{year}}$$

Since a wind turbine costs from \$3,000/kW to \$5,000/kW, a 100 kW unit costs around \$300,000 to \$500,000. With an additional 30% engineering and installation costs, the facility has to pay an average of \$571,428.57.

$$\text{Total project cost } (x) = \$300{,}000 + 0.3x \text{ and } \$500{,}000 + 0.3x$$

$$x = \frac{\$300{,}000}{0.7} = \$428{,}571.43$$

$$x = \frac{\$500{,}000}{0.7} = \$714{,}285.71$$

$$\text{Average project cost} = \frac{\$428{,}571.43 + \$714{,}285.71}{2} = \$571{,}428.57$$

C. Project Cash Flow

Efficiency Upgrades
Estimated project cost of the efficiency upgrades from The Cadmus Group, Inc. audit report is $109,114. Since MassSave provides $48,821 as a project grant, the net project cost for the efficiency upgrades becomes $60,293 with anticipated annual savings of $23,694. Moreover, the National Grid provides zero interest loans for 2.5 years.

C.1. The Pepperell Wastewater Treatment Facility

C.1.1. Solar
30% tax incentive does not apply to municipal wastewater treatment facility. Instead, MassDOER Gap Giant Incentive program provides estimated amount of $100,000 if the facility contributes a one-time investment of around $100,000 for the project.

$$\text{Remaining Cost: } \$767,115 - \$100,000 - \$100,000 = \$567,115$$

$$\text{Recurring Maintenance Fee: } \$2,350 \text{ (Averaged over 20 years)}$$

Every 20 years, the total maintenance cost is $47,000. $5,000 for testing the solar array systems every 5 years, $500 for data acquisition services each year, $500 for landscaping and cleaning each year, and $3,500 every 10 years to replace the inverter.

Applying Demand G-2 rate and Annual REC, the facility saves,

$$\text{First 10 years REC rate:} \frac{\$0.2}{\text{kWh}} \times \frac{210,000 \text{ kWh}}{\text{yr}} = \frac{\$42,000}{\text{yr}}$$

$$\text{Next 10 years REC rate:} \frac{\$0.03}{\text{kWh}} \times \frac{210,000 \text{ kWh}}{\text{yr}} = \frac{\$6,300}{\text{yr}}$$

$$\text{On} - \text{site generation savings:} \frac{\$29,610}{\text{yr}}$$

$$\text{Energy efficiency savings:} \frac{\$23,694}{\text{yr}}$$

$$\text{First 10 years savings:} \frac{\$95,304}{\text{yr}}; \text{ Next 10 years savings:} \frac{\$59,604}{\text{yr}}$$

Assuming the facility finances the project with 20 years loan program with average municipal interest rate of 2%, the facility's annual loan payments is as follows:

$$\text{Finance Efficiency Upgrades (0\% interest for 2.5years):} \frac{\$24,117}{\text{yr}}$$

$$\text{Finance Solar PV Installation (2\% interest for 20years):} \frac{\$28,922.87}{\text{yr}}$$

$$\text{Total annual loan payment (year } 1 - 2.5): \frac{\$53,039.87}{yr}$$

$$\text{Total annual loan payment (year } 3.5 - 20): \frac{\$28,922.87}{yr}$$

Cash flow analysis:

$$\text{Years } 1 - 2.5: \$95,304 - \$53,039.87 - \$2,350 = \frac{\$39,914.13}{yr}$$

$$\text{Years } 2.5 - 10: \$95,304 - \$28,922.87 - \$2,350 = \frac{\$64,481.13}{yr}$$

$$\text{Years } 11 - 20: \$59,604 - \$28,922.87 - \$2,350 = \frac{\$28,331.13}{yr}$$

The facility earns a total cumulative savings of $865,680 in 20 years after investing a one-time $100,000 for the project.

C.1.2. Wind

The MassCEC provides up to $150,000, which reduces the project cost to $421,428.57

$$\text{Estimated payback year: } \$421,428.57 \div \frac{\$15,002.55}{yr} = 28.1 \text{ years}$$

The average project cost for a 100 kW wind turbine is calculated to be $571,428.57. With the grant provided by MassCEC Commonwealth wind program,

$$\text{Remaining Cost: } \$571,428.57 - \$150,000 = \$421,428.57$$

$$\text{Maintenance/Repair/Operational Fees (3\% of Wind Project Costs): } \frac{\$17,143}{year}$$

Applying Demand G-2 rate and annual REC rate, the facility saves,

$$\text{20 years REC rate: } \frac{\$0.03}{kWh} \times \frac{106,401.1 \text{ kWh}}{yr} = \frac{\$3,192.03}{yr}$$

$$\text{On} - \text{site generation savings (heat \& electricity): } \frac{\$15,002.55}{yr}$$

$$\text{Energy efficiency savings: } \frac{\$23,694}{yr}$$

$$\text{Total anticipated savings: } \frac{\$41,888.58}{yr}$$

Assuming the facility finances the project with 20 years loan program with average municipal interest rate of 2%, the facility's annual loan payments is as follows:

$$\text{Finance Efficiency Upgrades (0\% interest for 2.5years):} \frac{\$24,117}{yr}$$

$$\text{Finance Wind Turbine Installation (2\% interest for 20years):} \frac{\$29,142.86}{yr}$$

$$\text{Total annual loan payment (year } 1-2.5): \frac{\$53,259.86}{yr}$$

$$\text{Total annual loan payment (year } 2.5-20): \frac{\$29,142.86}{yr}$$

Cash flow analysis:

$$\text{Years } 1-2.5: \$41,888.58 - \$53,259.86 - \$17,143 = -\frac{\$28,514.28}{yr}$$

$$\text{Years } 2.5-20: \$41,888.58 - \$29,142.86 - \$17,143 = -\frac{\$4,397.28}{yr}$$

The facility earns a total cumulative savings of negative $148,238 in 20 years.

C.1.3. Hydro

The annual Renewable Energy Certificate (REC) for hydropower is $0.025/kWh

$$\text{Amount of Saving:}$$

$$\text{Energy efficiency savings:} \frac{\$23,694}{yr}$$

$$\text{20 years REC rate:} \frac{\$0.025}{kWh} \times \frac{10,314.9kWh}{yr} = \frac{\$257.87}{yr}$$

$$\text{On} - \text{site generation savings :} \frac{\$1,454.40}{yr}$$

$$\text{Total anticipated savings:} \frac{\$25,406.27}{yr}$$

Assuming the facility finances the project with 20 years loan program with average municipal interest rate of 2%, the facility's annual loan payments is as follows:

$$\text{Finance Efficiency Upgrades (0\% interest for 2.5years):} \frac{\$24,117}{yr}$$

$$\text{Finance Wind Turbine Installation (2\% interest for 20 years)}: \frac{\$688.60}{yr}$$

$$\text{Total annual loan payment (year } 1-2.5): \frac{\$24,805.60}{yr}$$

$$\text{Total annual loan payment (year } 2.5-20): \frac{\$688.60}{yr}$$

Cash flow analysis:

$$\text{Years } 1-2.5: \frac{\$25,406.27}{yr} - \frac{\$24,805.60}{yr} = \frac{\$600.67}{yr}$$

$$\text{Years } 2.5-20: \frac{\$25,406.27}{yr} - \frac{\$688.60}{yr} = \frac{\$24,717.67}{yr}$$

The facility earns a total cumulative cash flow is $434,061 in 20 years.

C.1.4. Biomass

The total project cost is projected to be $5 million for a co-digestion AD/CHP system and MassCEC Commonwealth Organics-To-Energy program provides $400,000 as a grant.

$$\text{Remaining Cost: } \$5,000,000 - \$400,000 = \$4,600,000$$

Applying Demand G-2 rate and Annual Anaerobic Digestion/CHP REC, the facility saves,

$$\text{20 years REC rate:} \frac{\$0.03}{kWh} \times \frac{106,410 \text{ kWh}}{yr} = \frac{\$3,192.30}{yr}$$

$$\text{On}-\text{site generation savings (heat \& electricity)}: \frac{\$26,333.55}{yr}$$

$$\text{Energy efficiency savings:} \frac{\$23,694}{yr}$$

$$\text{Total anticipated savings:} \frac{\$53,219.85}{yr}$$

Assuming the facility finances the project with 20 years loan program with average municipal interest rate of 2%, the facility's annual loan payments is as follows:

$$\text{Finance Efficiency Upgrades (0\% interest for 2.5 years)}: \frac{\$24,117}{yr}$$

$$\text{Finance AD/CHP Installation (2\% interest for 20 years)}: \frac{\$234,600}{yr}$$

$$\text{Total annual loan payment (year } 1-2.5): \frac{\$258,717}{\text{yr}}$$

$$\text{Total annual loan payment (year } 2.5-20): \frac{\$234,600}{\text{yr}}$$

Cash flow analysis:

$$\text{Years } 1-2.5: \$53,219.85 - \$258,717 = -\frac{\$205,497.15}{\text{yr}}$$

$$\text{Years } 2.5-20: \$53,219.85 - \$234,600 = -\frac{\$181,380.15}{\text{yr}}$$

The facility earns a total cumulative savings of -$3,934,554 in 20 years.

C.2. The Southbridge Wastewater Treatment Facility

(**Note**: Southbridge Wastewater Treatment Facility does not have efficiency upgrades)

C.2.1. Solar
The maximum grant assistance for the project is about $100,000 and the facility has to contribute a one-time investment of $100,000 for the project.

$$\text{Remaining Cost: } \$4,472,000 - \$100,000 - \$100,000 = \$4,272,000$$

$$\text{Recurring Maintenance Fee: } \$2,350 \text{ (Averaged over 20 years)}$$

Every 20 years, the total maintenance cost is $47,000. $5,000 for testing the solar array systems every 5 years, $500 for data acquisition services each year, $500 for landscaping and cleaning each year, and $3,500 every 10 years to replace the inverter.

Applying Demand G-2 rate and annual Solar Renewable Energy Certificate (REC), the facility saves:

$$\text{First 10 years REC rate:} \frac{\$0.2}{\text{kWh}} \times \frac{1,377,729 \text{ kWh}}{\text{yr}} = \frac{\$275,548}{\text{yr}}$$

$$\text{Next 10 years REC rate:} \frac{\$0.03}{\text{kWh}} \times \frac{1,377,729 \text{ kWh}}{\text{yr}} = \frac{\$41,332}{\text{yr}}$$

$$\text{On}-\text{site generation savings:} \frac{1,377,729 \text{ kWh}}{\text{yr}} \times \frac{\$0.141}{\text{kWh}} = \frac{\$194,259}{\text{yr}}$$

$$\text{First 10 years savings:} \frac{\$469,808}{\text{yr}}$$

$$\text{Next 10 years savings:} \frac{\$235,591}{\text{yr}}$$

Assuming the facility finances the project with 20 years loan program with average municipal interest rate of 2%, the facility's annual loan payments is as follows:

$$\text{Finance Solar PV Installation (2\% interest for 20years):} \frac{\$85,440}{\text{yr}}$$

$$\text{Total annual loan payment (year } 1-20): \frac{\$213,600}{\text{yr}}$$

Cash flow analysis: the solar system needs $2,350 for maintenance annually

$$\text{Years } 1-10: \$468,808 - \$299,040 - \$2,350 = \frac{\$167,418}{\text{yr}}$$

$$\text{Years } 10-20: \$235,591 - \$299,040 - \$2,350 = \frac{\$-65,799}{\text{yr}}$$

The facility earns a total cumulative savings of $1,016,190 in 20 years after investing a one-time $100,000 for the project.

C.2.2. Wind

The MassCEC provides up to $150,000 for the wind project, which will reduce the project cost to $421,428.

$$\text{Maintenance/Repair/Operational Fees (3\% of Wind Project Costs):} \frac{\$17,143}{\text{year}}$$

Amount of Saving:

$$\text{20 years REC rate:} \frac{\$0.03}{\text{kWh}} \times \frac{100,000 \text{ kWh}}{\text{yr}} = \frac{\$3000}{\text{yr}}$$

On $-$ site generation savings (heat & electricity):

$$\frac{\$14,100}{\text{yr}}$$

$$\text{Total anticipated savings:} \frac{\$17,100}{\text{yr}}$$

Assuming the facility finances the project with 20 years loan program with average municipal interest rate of 2%, the facility's annual loan payments is as follows:

$$\text{Finance Wind Turbine Installation (2\% interest for 20years):} \frac{\$8,429}{\text{yr}}$$

$$\text{Total annual loan payment (year } 1-20): \frac{\$29,500}{\text{yr}}$$

Cash flow analysis: The wind turbine needs $17,143 for maintenance annually

$$\text{Years } 1-20: \$17{,}100 - \$29{,}500 - \$17{,}143 = -\frac{\$-29{,}543}{\text{yr}}$$

The facility earns a total cumulative savings of $-590,860 in 20 years.

C.2.3. Hydro

The renewable energy credit for hydropower is $0.025/kWh electricity generated.

Amount of Saving:

$$\text{20 years REC rate:} \frac{\$0.025}{\text{kWh}} \times \frac{29{,}484 \text{ kWh}}{\text{yr}} = \frac{\$737.1}{\text{yr}}$$

$$\text{On} - \text{site generation savings}: \frac{\$4{,}157}{\text{yr}}$$

$$\text{Total anticipated savings:} \frac{\$4{,}894.1}{\text{yr}}$$

Assuming the facility finances the project with 20 years loan program with average municipal interest rate of 2%, the facility's annual loan payments is as follows:

Cash flow analysis:

$$\text{(2\% interest for 20years):} \frac{\$774}{\text{yr}}$$

$$\text{Total annual loan payment (year 1} - 20): \frac{\$1{,}935}{\text{yr}}$$

$$\text{Years } 1 - 20: \frac{\$2{,}709}{\text{yr}}$$

The facility earns a total cumulative savings of $43,702 in 20 years.

C.2.4. Biomass

The cost of the project is about 10.32 million. The incentives is $400,000, and if the town pay $100,000 the rest is been financed.

$$\text{Remaining Cost: } \$10{,}320{,}000 - \$500{,}000 - \$100{,}000 = \$9{,}820{,}000$$

Applying Demand G-2 rate and annual Solar Renewable Energy Credits (REC), the facility saves:

$$\text{First 10 years REC rate:} \frac{\$0.03}{\text{kWh}} \times \frac{487{,}410 \text{ kWh}}{\text{yr}} = \frac{\$14{,}622.3}{\text{yr}}$$

$$\text{Next 10 years REC rate:} \frac{\$0.03}{\text{kWh}} \times \frac{487{,}410 \text{ kWh}}{\text{yr}} = \frac{\$14{,}622.3}{\text{yr}}$$

$$\text{On} - \text{site generation savings:} \frac{487{,}410 \text{ kWh}}{\text{yr}} \times \frac{\$0.141}{\text{kWh}} = \frac{\$68{,}724}{\text{yr}}$$

$$\text{First 10 years savings:} \frac{\$83{,}347}{\text{yr}}$$

$$\text{Next 10 years savings:} \frac{\$83{,}347}{\text{yr}}$$

Assuming the facility finances the project with 20 years loan program with average municipal interest rate of 2%, the facility's annual loan payments is as follows:

$$\text{Finance Solar PV Installation (2\% interest for 20years):} \frac{\$196{,}400}{\text{yr}}$$

$$\text{Total annual loan payment (year } 1 - 20\text{):} \frac{\$491{,}000}{\text{yr}}$$

Cash flow analysis:

$$\text{Years } 1 - 20\text{: } \$83{,}347 - \$196{,}400 = -\frac{\$-113{,}053}{\text{yr}}$$

C.3. The Millis Water Treatment Facility

C.3.1. Solar Power
Estimated Capital Costs:

$$\text{Remaining Cost: Solar Project Cost} - \text{ MassDOER Grant} \\ - \text{ Facility and Community Contribution}$$

$$\text{Remaining Cost: } \$1{,}085{,}600 - \$100{,}000 - \$100{,}000 = \$885{,}600$$

$$\text{Estimated payback years: } \$885{,}600 \div \frac{58{,}836}{\text{year}} = 15.05 \text{ years}$$

$$\text{Recurring Maintenance Fee: } \$2{,}350 \text{ (Averaged over 20 years)}$$

Every 20 years, the total maintenance cost is $47,000. $5,000 for testing the solar array systems every 5 years, $500 for data acquisition services each year, $500 for landscaping and cleaning each year, and $3,500 every 10 years to replace the inverter.

Estimated Revenue Streams:

$$\text{First 10 years REC rate:} \frac{\$0.20}{\text{kWh}} \times \frac{334{,}330.9 \text{ kWh}}{\text{year}} = \frac{\$66{,}866.18}{\text{year}}$$

$$\text{Next 10 years REC rate:} \frac{\$0.03}{\text{kWh}} \times \frac{334{,}330.9 \text{ kWh}}{\text{year}} = \frac{\$10{,}029.93}{\text{year}}$$

$$\text{Onsite generation savings } (\sim 334{,}330.9 \text{ kWh @ } \$0.17/\text{kWh}): \frac{\$56{,}836.25}{\text{year}}$$

Financing:

$$\text{Finance Efficiency Upgrades (0\% interest for 2.5 years):} \frac{\$5{,}990}{\text{year}}$$

$$\text{Finance Solar PV Installation (2\% interest for 20 years):} \frac{\$53{,}761}{\text{year}}$$

$$\text{Total annual loan payment (year } 1-2): \frac{\$59{,}751}{\text{year}}$$

$$\text{Total annual loan payment (year 3):} \frac{\$56{,}756}{\text{year}}$$

$$\text{Total annual loan payment (year } 4-20): \frac{\$53{,}761}{\text{year}}$$

$$\text{Total Estimated Annual Savings (years } 1-10): \$28{,}495 + \$56{,}836 + \$66{,}866 = \$152{,}197$$

$$\text{Total Estimated Annual Savings (years } 11-20): \$28495 + \$56836 + \$10030 = \$95{,}361$$

Cash Flow Analysis (including Maintenance Fee):

$$\text{Years } 1-2.5: \$152{,}197 - \$59{,}751 - \$2{,}350 = \frac{\$90{,}097}{\text{year}}$$

$$\text{Years } 2.5-10: \$152{,}197 - \$53{,}761 - \$2{,}350 = \frac{\$96{,}086}{\text{year}}$$

$$\text{Years } 11-20: \$95{,}361 - \$53{,}761 - \$2{,}350 = \frac{\$39{,}250}{\text{year}}$$

The facility earns a total cumulative savings of $1,338,387 after 20 years after investing a one-time payment of $100,000 for the project.

C.3.2. Wind Power

Estimated Capital Costs:

The MassCEC provides up to $150,000, which reduces the project cost to $421,428.57

$$\text{Estimated payback years: } \$421,428.57 \div \frac{\$13,583}{\text{year}} = 28.1 \text{ years}$$

The average project cost for a 100 kW wind turbine is calculated to be $571,428.57. With the grant provided by MassCEC Commonwealth wind program,

$$\text{Remaining Cost: } \$571,428.57 - \$150,000 = \$421,428.57$$

$$\text{Maintenance Fees (3\% of Wind Project Costs):} \frac{\$17,143}{\text{year}}$$

Estimated Revenue Streams:

With the Annual Wind Renewable Energy Credits (REC) considered, the facility saves,

$$\text{10 years REC rate:} \frac{\$0.03}{\text{kWh}} \times \frac{79,901.7 \text{ kWh}}{\text{year}} = \frac{\$2,397.05}{\text{year}}$$

$$\text{On} - \text{site generation savings (heat \& electricity):} \frac{\$13,583}{\text{year}}$$

$$\text{Total anticipated savings (including energy efficiency upgrades and RECs):} \frac{\$44,075}{\text{year}}$$

Financing:

Assuming the facility finances the project with 20 years loan program with average municipal interest rate of 2%, the facility's annual loan payments is as follows:

$$\text{Finance Efficiency Upgrades (0\% interest for 2.5 years):} \frac{\$5,990}{\text{year}}$$

$$\text{Finance Wind Turbine Installation (2\% interest for 20 years):} \frac{\$16,477}{\text{year}}$$

$$\text{Total annual loan payment (year 1} - \text{2):} \frac{\$22,467}{\text{year}}$$

$$\text{Total annual loan payment (year 2} - \text{3):} \frac{\$19,472}{\text{year}}$$

$$\text{Total annual loan payment (year 3} - \text{20):} \frac{\$16,477}{\text{year}}$$

Cash flow analysis:

$$\text{Years } 1 - 2.5: \$44{,}475 - \$22{,}467 - \$17{,}143 = \frac{\$4{,}865}{\text{year}}$$

$$\text{Years } 2.5 - 10: \$44{,}475 - \$16{,}477 - \$17{,}143 = \frac{\$10{,}855}{\text{year}}$$

$$\text{Years } 10 - 20: \$42{,}078 - \$16{,}477 - \$17{,}143 = \frac{\$8{,}458}{\text{year}}$$

The facility earns a total cumulative savings of $178,155 in 20 years.

D. GHG Emission Calculation

Assuming the coal produces 909grams or $9.09*10^{-4}$tons of CO_2 per kWh it generates and the natural gas produces 465grams or $4.65*10^{-4}$tons of CO_2,

D.1. The Pepperell Wastewater Treatment Facility

D.1.1. Solar

GHG Reduction:

$$\text{Coal} = 9.09 \times 10^{-4}\text{tons} \times \left(\frac{210{,}000 \text{ kWh}}{\text{yr}}\right) = 190.89\text{tons}$$

$$\text{Natural Gas} = 4.65 \times 10^{-4}\text{tons} \times \left(\frac{210{,}000 \text{ kWh}}{\text{yr}}\right) = 97.65 \text{ tons}$$

D.1.2. Wind

GHG Reduction:

$$\text{Coal} = 9.09 \times 10^{-4}\text{tons} \times \left(\frac{106{,}401.1 \text{ kWh}}{\text{yr}}\right) = 96.72\text{tons}$$

$$\text{Natural Gas} = 4.65 \times 10^{-4}\text{tons} \times \left(\frac{106{,}401.1 \text{ kWh}}{\text{yr}}\right) = 49.67\text{tons}$$

D.1.3. Hydro

GHG Reduction:

$$\text{Coal} = 9.09 \times 10^{-4}\text{tons} \times \left(\frac{10{,}314 \text{ kWh}}{\text{yr}}\right) = 9.38\text{tons}$$

$$\text{Natural Gas} = 4.65 \times 10^{-4}\text{tons} \times \left(\frac{10{,}314 \text{ kWh}}{\text{yr}}\right) = 4.80\text{tons}$$

D.1.4. Biomass

GHG Reduction:

$$\text{Coal} = 9.09 \times 10^{-4}\text{tons} \times \left(\frac{106{,}410 \text{ kWh}}{\text{yr}} + \frac{8{,}474\text{therms}}{\text{yr}} \times \frac{29.3 \text{ kWh}}{\text{therm}}\right)$$
$$= 322.42\text{tons}$$

$$\text{Natural Gas} = 4.65 \times 10^{-4}\text{tons} \times \left(\frac{106{,}410 \text{ kWh}}{\text{yr}} + \frac{8{,}474\text{therms}}{\text{yr}} \times \frac{29.3 \text{ kWh}}{\text{therm}}\right) = 164.93\text{tons}$$

D.2. The Southbridge Wastewater Treatment Facility

D.2.1. Solar

GHG Reduction:

$$\text{Coal} = 9.09 \times 10^{-4}\text{tons} \times \left(\frac{1{,}377{,}729 \text{ kWh}}{\text{yr}}\right) = 1{,}252 \text{ tons}$$

$$\text{Natural Gas} = 4.65 \times 10^{-4}\text{tons} \times \left(\frac{1{,}377{,}729 \text{ kWh}}{\text{yr}}\right) = 641 \text{ tons}$$

D.2.2. Wind

GHG Reduction:

$$\text{Coal} = 9.09 \times 10^{-4}\text{tons} \times \left(\frac{100{,}000 \text{ kWh}}{\text{yr}}\right) = 90.9\text{tons}$$

$$\text{Natural Gas} = 4.65 \times 10^{-4}\text{tons} \times \left(\frac{100{,}000 \text{ kWh}}{\text{yr}}\right) = 46.5\text{tons}$$

D.2.3. Hydro

GHG Reduction:

$$\text{Coal} = 9.09 \times 10^{-4}\text{tons} \times \left(\frac{29{,}484 \text{ kWh}}{\text{yr}}\right) = 26.75\text{ons}$$

$$\text{Natural Gas} = 4.65 \times 10^{-4}\text{tons} \times \left(\frac{29{,}484 \text{ kWh}}{\text{yr}}\right) = 13.71\text{tons}$$

D.2.4. Biomass

GHG Reduction:

$$\text{Coal} = 9.09 \times 10^{-4}\text{tons} \times \left(\frac{487{,}410 \text{ kWh}}{\text{yr}}\right) = 443\text{tons}$$

$$\text{Natural Gas} = 4.65 \times 10^{-4}\text{tons} \times \left(\frac{487{,}410 \text{ kWh}}{\text{yr}}\right) = 226.6\text{tons}$$

D.3. The Millis Water Treatment Facility

D.3.1. Solar Power

Potential Greenhouse Gas Reduction:

$$\text{Coal} = 9.09 \times 10^{-4}\text{tons} \times \left(\frac{260{,}000 \text{ kWh}}{\text{year}}\right) = 236.34 \text{ tons}$$

Or

$$\text{Natural Gas} = 4.65 \times 10^{-4} \text{tons} \times \left(\frac{260{,}000 \text{ kWh}}{\text{year}}\right) = 120.9 \text{ tons}$$

D.3.2. Wind Power

Potential Greenhouse Gas Reduction:

$$\text{Coal} = 9.09 \times 10^{-4} \text{ tons} \times \left(\frac{79{,}901.5 \text{ kWh}}{\text{year}}\right) = 72.63 \text{ tons}$$

$$\text{Natural Gas} = 4.65 \times 10^{-4} \text{ tons} \times \left(\frac{79{,}901.5 \text{ kWh}}{\text{year}}\right) = 37.15 \text{ tons}$$

References

"100 KW Wind Turbine Generator." *100 KW Wind Turbine Generator | Wind Energy Resources*. Wind Energy Resources, n.d. Web. 13 Feb. 2014.

"Air Emissions." Epa.gov. Environmental Protection Agency (EPA), 20 June 2013. Web. 24 Sept. 2013.

Allen, Gregory S. In-Conduit Hydropower Project. Rep. Holden: Alden Research Laboratory, 2013. Print.

Al-Megren, Hamid A. "HYDRODESULFURIZATION OF THIOPHENE OVER BIMETALLIC Ni–Mo SULFIDE CATALYSTS PREARED BY DIFFERENT METHODS." Kfupm.edu. The Arabian Journal for Science and Engineering, 12 Nov. 2008.Web. 05 Nov. 2013.

"ANAEROBIC DIGESTER – CONTROLLED TEMPERATURE." NRCS. NHCP, Sept. 2003. Web. 15 Nov. 2013.

Armannsson, Halldor. "06/00981 CO2 Emissions from Geothermal Power Plants and Natural Geothermal Activity in Iceland." Fuel and Energy Abstracts 47.2 (2006): 142. Print.

"Average Solar Radiation." PVEducation. Photovoltaic Education Network, n.d. Web. 16 Nov. 2013.

Babauta, Tony. "End of ARRA Fund Inflation to Decrease All SNAP." N.p., July 2012. Web. 20 Nov. 2013.

Barnard, Mike. "Wind Farm End of Life? Repowering or Benign Decommissioning." Barnard on Wind. WorldPress.com, 6 Mar. 2013. Web. 20 Feb. 2014.

Bengtson, Harlan. "The Flat Plate Heat Exchanger in Comparison with Other Types of Heat Exchangers." Brighthub Engineering. N.p., 25 May 2010. Web. 02 Dec. 2013.

Berkeley, Heather. "Line-item budget form". Town of Southbridge. N.d. 13. Feb. 2014

Bluhm, Alyssa. "How Much Do the Wind Turbines Cost." windustry.org. 2012., n.d. Web. 30 Sept. 2013.

Bossong, Kenneth. "Renewable Energy Provides 14% of US Electrical Generation During First Half of 2013." Renewable Energy World. N.p., n.d. Web. 24 Sept. 2013.

Bureau of Reclamation (USBR). "Reclamation Managing Water in the West----Hydroelectric Power", July 2005.

California. Energy Comission. VARIABLE-FREQUENCY DRIVE. California Energy
Commission, 15 Nov. 2000. Web. 30 Sept. 2013.

Claeys, Bram. "Grant Funding for Clean Energy Projects At Drinking Water and Wastewater
Facilities in Massachusetts." MassDEP. N.p., 28 Feb. 2014. Web. 5 Mar. 2014.

"Clean Water State Revolving Fund." Epa.org. Environmental Protection Agency (EPA), n.d.
Web. 24 Sept. 2013.

Chernicharo, C.A L. "Post-treatment Options for the Anaerobic Treatment of Domestic
Wastewater." Reviews in Environmental Science and Bio/Technology. Springer, 2006.
Web. 20 Feb. 2014.

Chris, Greacen. "A GUIDE TO PUMP-AS-TURBINE PICO-HYDROPOWER SYSTEMS."
MH Manual 1.2. N.p., 2013. Web. 21 Feb. 2014.

Cohen, Alvarez. "Anaerobic Digestion of Wastewater Sludge." Dartmouth Engineering. N.p., 4
Jan. 2010. Web. 19 Feb. 2014.

"Commonwealth Organics-to-Energy Program." Epa.gov. Environmental Protection Agency
(EPA), 10 Dec. 2013. Web. 18 Dec. 2013.

"Commonwealth Solar II." MassCEC. Mass Clean Energy Center, n.d. Web. 02 Dec. 2013.

"Commonwealth Wind Program." MassCEC. MassCEC, n.d. Web. 02 Dec. 2013.

"CO2 Now." Global Carbon Emissions. CO2Now, n.d. Web. 02 Dec. 2013.

"CO2 Emissions in 2012 Driven by China, Coal." Business Recorder. N.p., 25 Nov. 2013. Web.
02 Dec. 2013.

Cuttica, John J. "Combined Heat and Power (CHP) Is It Right For Your Facility?" Midwest CHP
Application Center. US DOE, 14 May 2009. Web. 17 Feb. 2014.

Cynthia, Greene. "Improving Energy Management at Water and Wastewater Utilities in
Massachusetts." Mass.gov. MassDEP, 2010. Web. 15 Sept. 2013.

"Data Show China Passing US as Biggest Oil Importer." CNBC.com. N.p., 10 Oct. 2013. Web.
02 Dec. 2013.

Devlin, Thomas D. "Commercial and Industrial CHP Technology Cost and Performance Data
Analysis for EIA." Meede.org. SAIC.Inc, June 2010. Web. 01 Nov. 2013.

"Dynamic Maps, GIS Data, & Analysis Tool." Nrel.gov. National Renewable EnergyLaboratory, 6 Feb. 2014. Web. 10 Jan. 2014."Energy Tips – Process Heating." Eere.energy.gov. Energy Efficiency and Renewable Energy, Sept. 2005. Web. 15 Nov. 2013.

"EPA's Clean Energy-Environment Tech Forum." The Keystone Center. Environmental Protection Agency, 15 Jan. 2009. Web. 5 Sept. 2013.

"Finally, U.S. Crude Production Exceeds Imports." Oil Patch Asia. N.p., 15 Nov. 2013. Web. 02 Dec. 2013.

Fthenakis, Vasilis. "Life Cycle GHG Emissions of Thin-film Photovoltaic Electricity Generation." *Bnl.gov*. N.p., 31 Jan. 2011. Web. 20 Jan. 2014.

Gaiusobaseki, Theophilus. "Hydropower opportunities in the water industry." INTERNATIONAL JOURNAL OF ENVIRONMENTAL SCIENCES. N.p., 03 Nov. 2010. Web. 05 Nov. 2013.

Ghose, Tia. "2013 Global Carbon Emissions to Reach Record Level." LiveScience.com. N.p., 19 Nov. 2013. Web. 02 Dec. 2013.

"Global Energy Statistical Yearbook 2013." World Energy Statistics. Enerdata, n.d. Web. 02 Dec. 2013.

"Global Trends in Renewable Energy Investment 2013." FS UNEP Centre. REN21, n.d. Web. 02 Dec. 2013.

Goldman, Peter. "HydroPower." Nrel.gov. U.S. Department of Energy, July 2004. Web. 15 Sept. 2013.

Green, Dino. "How Much Do Solar Panels Cost? – Updated Prices." Renewable Green Energy Power RSS. N.p., 25 Aug. 2012. Web. 30 Sept. 2013.

Green, Phil. "How Do You Space a Ground-mounted Array?" Civic Solar. N.p., 19 Dec. 2011. Web. 20 Feb. 2014.

Greenberg, Ely. "Energy Audits for Water and Watsewater Treatment Plants and Pump Stations." Continuing Education and Development, Inc, 2011 Web. 7 Oct. 2013

Grossman, Steven. State Revolving Fund Annual Report 2012. Rep. Massachusetts: MassDEP, 2012. Print.

Grossman, Steven. State Revolving Fund Annual Report 2013. Rep. Massachusetts: MassDEP, 2013. Print.

Hatch, Orrin. "THE AMERICAN RECOVERY AND REINVESTMENT ACT OF

2009."Waysandmeans.house.gov/. House Ways and Means Committee, 12 Feb. 2009. Web. 04 Nov. 2013.

"How Efficient Are Wind Turbines?" Global Wind Day. European Wind Energy Association, n.d. Web. 15 Nov. 2013.

"HVACR Service Troubleshooting with the Professor: Part 2 Get Insight from John Tomczyk in This Free EBook Covering a Wide Range of Service and Troubleshooting Topics." Plate Heat Exchanger: How Does It Work? N.p., 14 Nov. 2000. Web. 02 Dec. 2013.

"Hydroelectric Project Price Questionable." Kaieteur News. Ed. Knews. GxMedia, 9 May 2010. Web. 30 Sept. 2013.

Iacovidou E. "Food Waste Co-digestion with Sewage Sludge." *Journal of Environmental Management*. Elsevier, 26 July 2012. Web. 20 Jan. 2014.

"Introduction To DG." Dnrec.delaware.gov. The Delaware Department of Natural Resources and Environmental Control (DNREC), 20 Jan. 2010. Web. 05 Nov. 2013.

"Is AD Right For Me?" ADIAC. Anaerobic Digestion Initiative Advisory Committee, 2009. Web. 15 Nov. 2013.

Jeandenis, Howard. "Small Wind: How Much Do Home Wind Turbines Cost?" *Green Buildings*. LEED Green Associate, 2010. Web. 10 Jan. 2014.

Jensen, Torben Kvist. "Biogas to the Natural Gas Grid." *Intelligent Gas Technology*. Danish Gas Technology Centre, 27 May 2010. Web. 20 Jan. 2014.

Jones, Sharon M. *Pepperell Wastewater Treatment Facility Process Evaluation*. Rep. The Cadmus Group, Inc., 20 Sept. 2012. Web. 31 Jan. 2014.

Jorgenson, Bill. "Patrick-Murray Administration Launches New Clean Energy Program." Agreen Energy, LLC. N.p., 16 Nov. 2011. Web. 2 Dec. 2013.

Kelly-Detwiler, Peter. "As Solar Panel Efficiencies Keep Improving, It's Time to Adopt Some New Metrics." Forbes. Forbes Magazine, 16 July 2013. Web. 24 Sept. 2013.

Ketema. "Basic Construction of Shell and Tube Heat Exchangers." Alfalaval. Alfalaval, Oct. 2007.   Web. 5 Nov. 2013.

Kindersley, Dorling. "Hydropower." National Geographic, n.d. Web. 24 Sept. 2013.

Krasnecky, Paul. Veolia Group. Southbridge Wastewater Treatment Facility Town of Southbridge, January. 2013.

Lalander, Emilia. Modelling Hydrokinetic Energy Resource for In-stream Energy Converters. Rep. Uppasala: Uppsala University, 2010. Print.

Lebo, John. "Heat Recovery Water Heating." Doucette Industries, Inc, May 2001. Web. 9 Oct. 2013.

Lines, James R. "Heat Exchangers in Municipal Wastewater Treatment Plants." Graham. N.p., 2013. Web. 5 Nov. 2013.

"Local Government Climate and Energy Strategy Guide." Envionmental Protection Agency, 2012. Web. 6 Oct. 2013.

Manno, Michele. "Hydraulic Turbines and Hydroelectric Power Plants." University of Rome, 22 May 2013. Web. 20 Feb. 2014.

"Massachusetts Energy Management Pilot Program for Drinking Water and Wastewater Case Study." Epa.gov. Environmental Protection Agency (EPA), Dec. 2009. Web. 15 Sept. 2013.

"Mass Save Energy Saving Programs." Mass Save. The RCS Network, 3 Mar. 2011. Web. 24 Sept. 2013.

Mcgee, Mike. "Wastewater Technology Fact Sheet Fine Bubble Aeration." Epa.org. U.S. Environmental Protection Agency, Sept. 1999. Web. 15 Sept. 2013.

McGovert, Morgan. "PowerWorks 100 KW Wind Turbines." PowerWorks, 25 June 2013. Web. 18 Feb. 2014.

"Model As-of Right Zoning Ordinance or Bylaw: Allowing Use of Wind Energy Facilities."*DSIRE USA*. DSIRE, n.d. Web. 19 Feb. 2014.

Morales, Alex. "Renewable Energy Investments Shift to Developing Nations." Bloomberg Businessweek. Bloomberg, 12 July 2013. Web. 2 Dec. 2013.

Moreno, Laura. "CO-DIGESTION ECONOMIC ANALYSIS TOOL (COEAT)."Epa.gov. Environmental Protection Agency (EPA), July 2010. Web. 03 Nov. 2013.

Newton, Jim. "Kent County's Heat-Recovery Energy System." Kent County, Aug. 2011. Web. 8 Oct. 2013

Noller, Herbert. "An Analysis of Energy Production Costs from Anaerobic Digestion Systems on U.S. Livestock Production Facilities." *Natural Resources Conservation Service*. The US Department of Agriculture, 1 Oct. 2007. Web. 31 Jan. 2014.

Perez, Susan. "State Revolving Fund Annual Report." Mass.gov. MassDEP, 28 Sept. 2012. Web. 20 Sept. 2013.

"Пазарна информация." Сага Комодитис. Saga Commodities, n.d. Web. 02 Dec. 2013.

"Plate Heat Exchanger." Grainger. N.p., n.d. Web. 10 Nov. 2013.

"Plate Heat Exchangers." Alfalaval. N.p., n.d. Web. 02 Dec. 2013.

"Plate Heat Exchangers." Plate Heat Exchangers. N.p., n.d. Web. 02 Dec. 2013.

"Plate Heat Exchanger: How Does It Work?" The News Magazine. N.p., 11 Dec. 2000. Web. 02 Dec. 2013.

Pless, Shanti. "Net-Zero Energy Buildings: A Classification System Based on Renewable Energy Supply Options." National Renewable Energy Laboratory. N.p., June 2010. Web. 25Nov. 2013.

"PowerWorks Wind Turbines, American Made 100 KW Wind Turbine Sales, New Used Rebuilt

"REN21's Renewables Global Status Report 2013." Worldwatch Institute. REN21, n.d. Web. 02 Dec. 2013.

"Renewable Energy Certificates." EPA. Environmental Protection Agency, 3 Sept. 2008. Web. 20 Feb. 2014.

"Renewable Energy Fact Sheet: Low-Head Hydropower from Wastewater." Epa.gov. Environmental Protection Agency (EPA), Aug. 2013. Web. 05 Nov. 2013.

Riedell, David G. State Revolving Fund Annual Report 2010. Rep. Massachusetts: MassDEP, 2010. Print.

Reichle. "FAA NOTIFICATION INVESTIGATION." Turnermillergroup. CHA, 20 June 2013. Web. 20 Feb. 2014.

Roger, James. "Energy Efficiency and Renewable Energy Opportunities at Water and Wastewater Facilities." Mass.gov. Commonwealth of Massachusetts, July. 2010. Web. 24 Sept. 2013.

Sandru, Ovidiu. "Distance Between Wind Turbines Should Be Doubled, Researchers Say." The Green Optimistic, 22 Jan. 2011. Web. 18 Feb. 2014.

Schultz, Richard A. "Low Head Hydro Powers Wastewater Plant." Water and Waste Digest. N.p., 28 Dec. 2000. Web. 05 Nov. 2013.

Smyth, Elizabeth. "T12 Phase-Out in July." Precision P2 Paragon. Echo, 19 Mar. 2012. Web. 20 Nov. 2013.

"Solar Carve-Out / SRECs." Solar Carve-Out. Mass EEA, n.d. Web. 02 Dec. 2013.

"SRoeCo Solar." SRoeCo Solar RSS. N.p., n.d. Web. 02 Dec. 2013.

Spentzas, Steve. "Optimization of a Cogeneration System in the Automotive Industry."
    www.midwestcleanenergy.org. Energy Resources Center, 2006. Web. 15 Sept. 2013.

Strecker, Romain. "Boston Solar Energy Blog." Solar Panels. N.p., n.d. Web. 24 Sept. 2013.
    "T12 Phase-Out in July." T12 Phase-Out in July. N.p., 19 Mar. 2012. Web. 02 Dec. 2013.

Stevens, Laurie. "Pepperell Dept. of Public Works." Pepperell Dept. of Public Works. Town of
    Pepperell, Mar. 2008. Web. 08 Feb. 2014.

"Summary of Changes to the Commonwealth Wind Program." *MassCEC*. Massachusetts Clean
    Energy Center, 9 July 2013. Web. 19 Feb. 2014.

"Sustainability and the Clean Water State Revolving Fund." EPA.org. Environmental Protection
    Agency (EPA), 12 July 2012. Web. 21 Nov. 2013.

"The Pros and Cons of Solar Leasing." Ameco Solar The Pros and Cons of Solar Leasing
    Comments. N.p., 20 June 2013. Web. 02 Dec. 2013.

Turgeon, Jason. "EPA Programs to Promote Water and Wastewater Energy Efficiency." EPA, 18
    Mar. 2013. Web. 20 Jan. 2014.

Turnia, Onur. "How Much of a Load Does a Solar Array Add to a Roof?" *Civic Solar*. N.p., 15
    Feb. 2012. Web. 15 Jan. 2014.

United Nations Environment Programme (UNEP), "Thermal Energy Equipment: Cogeneration",
    2006

United States. Environmental Protection Agency. The Benefits of Anaerobic Digestion of Food
    Waste At Wastewater Treatment Facilities. Environmental Protection Agency, 2007.
    Web.

United States. Environmental Protection Agency. Low-Head Hydropower from Wastewater.
    EnvironmentalProtection Agency, Aug. 2013. Web. 13 Nov. 2013.

United States. Environmental Protection Agency. Fine Bubble Aeration. Environmental
    Protection Agency, Sept. 1999. Web. 22 Nov. 2013

"U.S. Energy Information Administration - EIA - Independent Statistics and Analysis."
    International   Energy Outlook 2013. U.S Energy Information Administration, 25 July
    2013. Web. 01 Dec.   2013.

"WATER & SEWER RATE HEARING Town of Pepperell Department of Public Works."
    Department of Public Works. Sewer & Wastewater Management Division, Dec. 2012.
    Web. 05 Dec. 2013.

Wenlock. "Shell and Tube." Armstrong. N.p., 2011. Web. 15 Nov. 2013

Western Resource Advocates. "THE WATER-ENERGY NEXUS in Coloradan Communities."
    (n.d.): n. pag. Web.

"What Is Anaerobic Digestion?" American Biogas Council. American Biogas Council, n.d. Web.
    03 Dec. 2013.

"Wind Energy: Facts." Wind Energy: Facts. Office of Energy and Environmental Affairs, n.d.
    Web. 24 Sept. 2013.

Wind Turbines." *PowerWorks Wind Turbines, American Made 100 KW Wind Turbine Sales,
    New Used Rebuilt Wind Turbines*. N.p., n.d. Web. 17 Feb. 2014.

"Wind Turbines." Wind Turbines. Wind Measurement Information (WMI). 2013.Web. 24
    Sept. 2013.

Wong, Shutsu Chai. "Tapping the Energy Potential of Municipal Wastewater Treatment:
    Anaerobic Digestion and Combined Heat and Power in Massachusetts." Mass.gov.
    MassDEP, July 2011. Web. 01 Nov. 2013.

"Ten Things to Know Before Going Solar." Solar Energy. Cooler Planet, 18 Mar. 2009. Web. 16
    Nov.2013.

"THE ARRA AND SRF QUESTIONS AND ANSWERS." Accg.org. Environmental Protection
    Agency (EPA), 17 Mar. 2009. Web. 04 Nov. 2013.

Turnia, Onur. "How Much of a Load Does a Solar Array Add to a Roof?" *Civic Solar*. N.p., 15
    Feb. 2012. Web. 15 Jan. 2014

"Types of Fuel Cells." Eere.energy.gov. Energy Efficiency and Renewable Energy, 03 Aug.
    2011. Web. 04 Nov. 2013.