Feasibility Study for Effluent Thermal Energy Recovery at the Ithaca Area Wastewater Treatment Facility

CEE 5910 Final Report

Spring 2019

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Advisor's Introduction

As faculty member in the School of Civil & Environmental Engineering at Cornell University, I am pleased to write this introduction to the study that follows, "Feasibility Study for Effluent Thermal Energy Recovery at the Ithaca Area Waste Water Treatment Facility." I have had the pleasure of working with eight students in our program: four from environmental engineering, three from engineering management, and one from civil engineering.

Effluent Thermal Energy Recovery, or ETER for short, represents a potential source of renewable energy that to date has not been greatly exploited in the U.S. ETER can be accessed in sewer mains as they pass through the metropolis, but treatment plants are an especially beneficial location, since the flow is so concentrated at that point, on the order of millions of gallons per day, or more. Heat pumps introduced into the flow have the advantage that capital costs are lowered compared to digging trenches or wells. The heat extracted can be used internally within the wastewater treatment operation, or exported to adjacent loads.

Working with our partner Dr. Jose Lozano, Laboratory Director at IAWWTF, the student team has assessed the size of the resource, the demands of possible loads, and technologies that might be appropriate. They have also conducted an economic analysis of the project and estimated greenhouse gas reductions. They have also considered how ETER might combine with other sustainable options such as combined heat and power based on methane produced from a biodigester, or a possible commercial-scale solar PV array installed at the plant.

In closing, the reader should be aware that this study was conducted for educational purposes. The values contained in this report should not be used as a basis for decision-making about a specific ETER project, as up-to-date costs for specific regions are needed for that purpose. On behalf of the team, I wish to thank Jose and his assistants Gabrielle Hollfelder and Roxanne Roberts for their assistance during this project and for the opportunity to work with them on this promising technology. While their input is gratefully acknowledged, the contents of this report do not represent the official positions of the Ithaca Area Waste Water Treatment Facility or Cornell University, and responsibility for any and all errors and omissions rests with the team and myself.

Yours in sustainability,

Francis M Vanek, PhD
Senior Lecturer and Research Associate

Executive Summary

The purpose of this report is to understand and analyze the implementation of an Effluent Thermal Energy Recovery (ETER) system at the Ithaca Area Wastewater Treatment Facility (IAWWTF). ETER is a developing technology that can extract heat from wastewater for distribution to an internal or external system. Many examples and applications of ETER technology exist within and outside of the United States. For this report, a team of Cornell University engineering students focuses on the significance of carbon emissions from fossil fuels and calculates economic and environmental outputs for an ETER system at IAWWTF over a 30-year investment horizon. By determining the basic components, system capacity, sources and uses of energy, and developing a comprehensive model that integrates options for a solar photovoltaic (PV) array, the team is able to make recommendations for IAWWTF.

Using provided and researched information, the team analyzes the viability and benefits of ETER at IAWWTF. ETER could produce enough heat to thoroughly dry sludge output at the plant, saving at least $250,000 in annual landfill fees. Furthermore, any additional heat could be used for ongoing operations or sold to the nearby City Harbor development. In addition, implementing solar panels at IAWWTF would enable the plant to take a large step towards energy independence, and this is found to be a cost-effective approach to reducing carbon emissions. While ETER and solar have high capital costs, the analysis shows that the investment may pay off over time because of sludge drying savings and relatively low operational costs.

The team suggests that IAWWTF further study the implementation of both ETER and solar in order to achieve optimal results. A 660-kW heat pump for the ETER system would reduce CO_2 at a cost of $90.75/ton. Combining the technologies can save IAWWTF about 590,000 kg of CO_2 per year relative to the business-as-usual scenario with a sludge drying system powered entirely by natural gas. It is also recommended that IAWWTF prioritize the installation of a solar array because of its relatively low cost of reducing CO_2 at $35.11/ton. Further research should be performed to optimize the allotted space for solar around the facility, which would increase installation capacity and reduce the carbon footprint of the electrical input for ETER. Finally, it is important to secure a low total installation for ETER if possible, as sensitivity analyses reveal that this is a critical factor in determining economic viability. However, conservative estimates and studies of other plants show potential for a return on investment between 6 and 10 years, which can be improved by exploring options to sell dried sludge to various end-users.

Motivation for the Topic

Effluent Thermal Energy Recovery (ETER) is a developing technology that extracts heat from wastewater and distributes that heat to an internal or external system. This technology can save carbon emissions and move the Ithaca community closer to ‘greener’ energy sources. ETER is utilized in U.S. water treatment facilities including those in Philadelphia and Chicago, where the technology implementation has been successful. With this project, a student team of engineers from Cornell University examines the feasibility of implementing ETER in the Ithaca Area Wastewater Treatment Facility (IAWWTF). The team members for this project have diverse backgrounds encompassing Civil Engineering, Water Resources, Environmental Engineering, Construction Management, and Engineering Management. Emphasis is placed on discovering and assessing ‘greener’ and more creative solutions for deriving energy in order to meet the triple bottom line challenges in today’s world. This report provides an in-depth exploration of the technological, environmental, economic, and social impacts of ETER.

Goals of the Project

The goal of the Spring 2019 CEE 5910 project is to determine the feasibility of ETER in the context of the IAWWTF. Specifically, this project outlines the amount of heat that can be extracted from the wastewater, the corresponding reduction in greenhouse gas emissions from fossil fuels, and optimal decisions relating to the distribution of that heat to internal and external stakeholders.

Individual Background of Team Members

Shuyao Cai is from Shenzhen, China. After completing her undergraduate studies in Water Resources, she is now studying in Cornell University’s department of Environmental Engineering for her Master of Engineering degree in Water Resources. Shuyao will graduate in May 2019.

Andrew Kang is from New City, NY. He received his undergraduate degree in Environmental Engineering from Cornell University and he is currently pursuing his Master’s degree in Engineering Management. He wants to pursue a career in construction and sustainability. Andrew will graduate in May 2019.

Victor Khong is from Hong Kong. He received his undergraduate degree in Civil and Environmental Engineering from The University of California, Berkeley and is currently pursuing his Master of Engineering degree in Environmental Engineering at Cornell University. Victor will graduate in May 2019.

Mingdi Li is from Tianjin Province, China. She received her undergraduate degree in Environmental Engineering at Tianjin University and currently is in the process of getting her Master of Engineering degree in Environmental and Water Resources Engineering at Cornell University. Mingdi will graduate in May 2019.

Saurav Sharma is from Kathmandu, Nepal. He is currently pursuing his undergraduate degree in Civil Engineering at Cornell University. Saurav will graduate in May 2019. Upon graduation, Saurav plans to work in the field of road construction and eventually switch to project management.

Ken Shimizu is from Edina, MN. He received his undergraduate degree in Civil Engineering from Cornell University and is currently pursuing his Master of Engineering degree in Engineering Management. Upon graduation in May 2019, Ken plans to work in the field of real estate, construction, and infrastructure consulting.

Katie White is from Pittsburgh, PA. She received her undergraduate degree in Civil Engineering from Cornell University and is currently pursuing her Master of Engineering degree in Engineering Management. Katie will graduate in May 2019.

Zixian Zhu is from Anhui Province, China. She completed her undergraduate degree in Construction Management at Beijing Jiaotong University. Currently, she is finishing her Master of Engineering degree in Engineering Management at Cornell University and will graduate in May 2019.

Scoping Statement and Clarifying Assumptions

Considering the motivation behind this study, the reduction in greenhouse gas emissions due to the introduction of the ETER in IAWWTF is determined. This requires an in-depth lifecycle analysis of the plant and research on the equipment that will be used in a proposed ETER system. The thermodynamics within the system are investigated, including the heat transfer between the wastewater and the equipment, heat extraction coefficients of the different metals that make up the equipment, and the energy required to power the heat pump.

Another important consideration is the economic feasibility of the plant. The plant should ideally be sustainable such that the revenue or savings generated is greater than the cost incurred from producing ETER heat. This requires an examination of the industrial equipment that is included in the design system. A financial analysis is conducted to ensure that the ETER system is viable and attractive for IAWWTF financially, whether that involves distribution of heat to internal stakeholders, external stakeholders, or a combination of these two parties.

Finally, conclusions and recommendations are provided at the end of the study. Since the goal is to optimize the benefits of the ETER system, the team examines how the different perspectives are directly impacted from the introduction of the system and whether all of the economic, environmental, and social components will benefit from ETER or other clean energy sources like solar PV arrays.

Topics Explicitly Included in This Study

- **System capacity and fundamental components required**. Analysis of best equipment or vendors is not included in this study.
- **Decision variables optimizing the distribution of ETER heat**. The potential end-users include City Harbor and IAWWTF. City Harbor is a real estate development located near the plant and may use ETER for space or water heat, while IAWWTF may use ETER for space heat, water heat, or additional heat for its sludge drying process.
- **Financial and environmental analysis of multiple scenarios**. These are the primary objective functions and constraints that will be included in this study. CO_2 from fossil fuels is the focus of environmental emissions.
- **Capital and operating costs for ETER and solar**. These values are determined and compared to the business-as-usual scenario using NPV, Levelized Cost of Electricity (LCOE), and Levelized Cost of Heat (LCOH) metrics.

Topics Explicitly Excluded from This Study

- **Decision variables for system design**. A basic system, including heat pumps, equipment, and distribution components is outlined based on the parameters of the treatment plant and the amount of heat that can be extracted, but the reliability or optimality of specific components is not analyzed.
- **The availability of energy sources from previously proposed microgrids**. Only ETER, solar, natural gas, and existing methods of heat energy production at IAWWTF are considered as available heat energy sources in this project.
- **Political barriers to implementation**. While social implications may be mentioned in this report, political barriers to implementing ETER are not addressed.
- **Specific sources of debt and equity financing for ETER**. Sources of capital for implementing ETER are not explicitly identified, although the cost of capital may be assumed based on comparable projects and cost of debt for the plant.

Key Assumptions

- There are no capital cost barriers for ETER.
- A fixed price exists for heat sold to City Harbor.
- ETER technology runs, on average, 90% of the time to allow for downtime and maintenance; actual running time will vary slightly depending on demand.
- A discount rate is determined and further verified using the cost of capital for the plant.

Market Analysis

Technology and Equipment

Heat Pumps

Heat pumps consist of industrial equipment that can increase the temperature of a waste-heat source to a level at which the waste heat becomes useful. The waste heat can then replace purchased energy and lower energy costs. Heat pumps require an external mechanical or thermal energy source.

All heat pumps perform the same basic function: receive the heat from the waste-heat source, increase the waste-heat temperature, and deliver the useful heat at the elevated temperature. The wastewater is delivered to the evaporator to be vaporized. Then, the compressor increases the pressure of the working fluid, which increases the condensing temperature. Finally, the working fluid condenses in the condenser to deliver high temperature heat to the heat sink.

The heat pump can reduce energy costs when the cost of energy to operate is less than the value of the energy saved and the net operating cost savings are sufficient to pay back the capital investment in an acceptable time. The payback periods for heat pumps are typically 2 to 5 years, but this can vary with the functions of different heat pumps.

There are many different types of heat pumps: Closed-cycle mechanical heat pumps, open-cycle mechanical vapor compression heat pumps, open-cycle thermocompression heat pumps, and closed-cycle adsorption heat pumps. Because of objectives involving process and water heating, operational space heating, and large-scale space heating, the two types the team focuses on are the closed-cycle mechanical compression and the closed-cycle adsorption. Closed-cycle applications have a drying range of about 1 to 20 mmBTU/h of heat output. The vapor compression evaporation delivers about 20 mmBTU/h to 100 mmBTU/h.

When choosing a heat pump, there are several critical questions: where is heat available from the process, where is the heat required, what is the value of saved energy, and will the facility gain non-energy benefits such as environmental improvements? A cost/benefit analysis needs to be conducted along with a detailed feasibility study to define the benefits and costs, and this is explored later in this report. There are 3 things that must be considered when choosing a heat pump: the nature of the heat source, the nature of the heat sink, and the required temperature lift. In the case of IAWWTF, the nature of the heat source is a liquid (wastewater). The nature of the heat sink is also a liquid (space heating; air). The required temperature is about 80 to 90°C (176 to 194°F)

GEA provides industrial heat pumps for all types of industries. Their pumps are customizable for closed cycle and adsorption. Some of the benefits to using these pumps include a reduction in energy consumption, high supply temperatures in combination with high output, environmental friendliness from the use of natural refrigerants, a 20-year lifecycle, profitable amortization period, and low overall operation costs. Compression heat pumps from GEA offer condensation temperatures that are effective not only for operation of the low temperature heating system, but also for the supply of process heat.

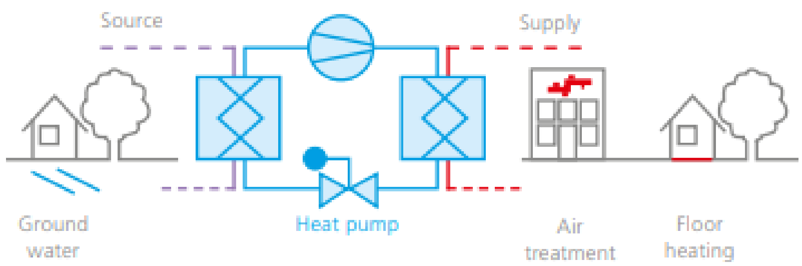

Figure 1. Heat Pump Flow Diagram.

Thermax is also a supplier of heat pumps. The Thermax heat pumps utilize steam, hot water, exhaust, fuel, geothermal energy or any combination of these sources to pump heat. These are typically used for district heating applications. These heat pumps can bring hot water up to 90°C (194°F) and have a COP ranging between 1.65 and 1.75.

It is difficult to obtain a financial estimate or quotes of a specific heat pumps without additional specifications from IAWWTF. The ranges are too vast to be able to deduce the cost of a specific heat pump that can handle 75 gal/min and heat water up to 80-90°C (176-194°F). However, the economic analysis in this report addresses this problem by examining the capacities and costs of comparable systems.

Expansion Valves

Thermal expansion valves (TEVs) are used in refrigeration and air conditioning systems and control the amount of working fluid released into the evaporator to keep the heat. TEV is a key element for heat pumps. It has a sensing bulb that is connected to the line of the piping so that the temperature of the refrigerant that leaves the evaporator can be sensed. The liquid must take time inside the evaporator to cool down or heat up. Therefore, the valve lowers the flow to give the fluid ample time to change its temperature.

The cost of an expansion valve ranges between $50 and $500 depending on the installation, the type of valve, and the type of system for implementation. There are many suppliers of valves, and there are also many types of valves. Danfoss and Thermax supply valves, which vary in pricing. However, more system specifics are required to be able to conclusively agree on the type and size of valve needed.

Heat Exchanger

A heat exchanger is a device that efficiently transfers heat from one source to another. There are many different types of heat exchangers such as, liquid to air, air to liquid, liquid to liquid, and air to air. They can be distinguished from the direction of working fluid flow. There is parallel flow, crossflow, and countercurrent. In parallel flow, both fluids move in the same direction. In cross flow, the fluids run perpendicular from each other. And in countercurrent flow, the fluids move in opposite directions from each other.

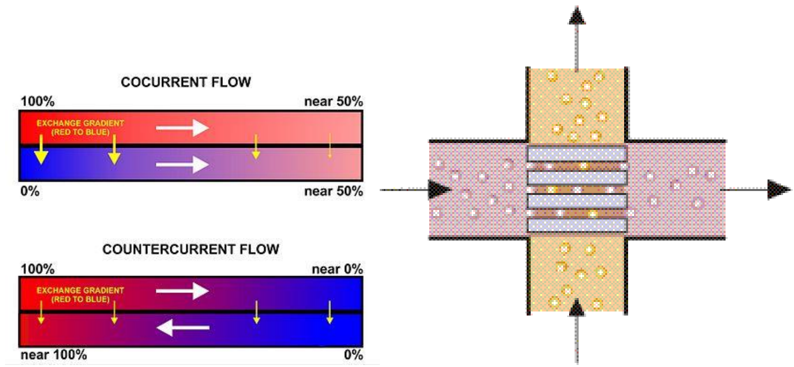

Figure 2. Concurrent, Parallel (left) and Cross Flow (right).

There are many different types of heat exchangers: shell and tube, plate heat, regenerative heat, and adiabatic wheel. The shell and tube heat exchanger consists of multiple tubes which the fluid runs through. The first set of tubes contains the fluid that needs to be heated, while the second set is responsible for activating the heat exchange and transmitting its own heat to the liquid. The plate heat exchanger consists of thin plates with a small amount of space between the plates. The large surface area allows fluid to run in between the plates and ultimately transfer heat. It also allows the liquid to cool down or heat up more efficiently than it would when using the shell and tube.

The regenerative heat exchanger can be either a shell and tube or plate heat exchanger, but the same fluid is passed along both sides of the exchanger. A large amount of energy is saved in this system because the process is cyclical, and almost all the relative heat is transferred. Only a small input of energy is needed to raise and lower the overall temperature. Lastly, the adiabatic wheel heat exchanger consists of an intermediate fluid that is used to store heat. This then transferred to the other side of the exchanger to heat the other fluid.

There are many suppliers of heat exchangers such as GEA, Thermax, Emerson, and Lytron. Lytron specializes in thermal solutions and have a wide variety of heat exchangers that can be utilized in our system. Again, while vendor quotes were not available for this project, an expected price for the ETER system at IAWWTF is estimated and supplemented by a sensitivity analysis in the economic section of this report. GEA has a specific product called a Varitube tubular heat exchanger that is specifically designed for the thermal treatment of low to high viscosity products that contain particles, pulp, and fibres. This is a shell and tube heat exchanger, which can be customized to be corrugated, further increasing the thermal efficiency of the heat exchanger.

Energy Recovery within Wastewater Treatment Facilities

Chicago, Illinois

Chicago has the world's largest water treatment plant which treats 1.2 billion gallons per day. It has implemented a Sewage Heat Recovery process at its Kirie facility, commencing operations in May of 2012[1]. In the first six months, it halved the plant's electricity usage. With the system's capital cost of $175,000, the plant has estimated a payback period of less than 8 years. The system is relatively simple; the wastewater that travels to the treatment plant from showers, dishwashers, toilets and other sources is typically around 60°F. A heat pump is used to transfer this heat to clean water for the purpose of building heating needs, including showers, dishwashers, or even radiators. The system is closed loop, so the clean water is never contaminated by the wastewater. In most facilities, this heat is wasted as it takes much more energy to heat cold water than water that is already at 60°F. Additionally, the heat pumps can be reversed in the summer, which heats the wastewater to reduce a building's cooling costs.

Chicago's Metropolitan Water Reclamation District is aiming to reduce energy costs through anaerobic digestion, which harvests gas produced by bacteria and helps break down components of wastewater. The district already gets nearly a third of its energy from this process, it is aiming to invest $10 million to expand efforts at the Calumet plant in Chicago's South Side. Local businesses, such as breweries, will pay the plant to take their waste for anaerobic digestion. This will produce methane which can then be sold back to the grid. If the process is successful at this plant, it will be incorporated at Stickney, which could produce enough energy to offset 75% of its total energy use.

Gresham, Oregon

In April of 2015, Gresham, Oregon's wastewater treatment facility achieved Net Zero Energy status. 92% of its energy consumption is produced from converting organic matter sludge into biogas. Most of this organic matter comes from wastewater filled with fats, oils, and grease that is trucked in from Portland-area restaurants. The biogas is fed into two powerful engines that convert it into heat and electricity that can be used at the plant; any excess electricity is returned to the grid. The remaining 8% of its energy needs come from a ground mounted solar array. It is estimated that these technologies save an average of $500,000 per year and generate an annual revenue of about $250,000 from the waste accepted from local food establishments.

This plant receives approximately 13 million gallons of wastewater per day, which is about twice the input of the IAWWTF but a more realistic comparison than the system in Chicago. The plant's operations are similar to operations at the IAWWTF and begin with Primary Treatment, where the sludge is removed for the purposes of conversion to biogas. Next, Aeration helps the bacteria break down organic matter and remove contaminants. Then, Secondary Clarification removes

[1] Metropolitan Water Reclamation District of Greater Chicago (2019).

any remaining sludge. Next, Disinfection ensures that the water leaving the plant meets EPA regulations. Finally, the Plant Effluent Phase discharges water into the Columbia River.

External District Energy Applications and Economics

ETER technology is also currently used to power portions of energy districts. The energy produced using ETER is used for space heat and hot water for buildings. Often, these energy districts do not derive the entirety of their capacity from ETER, and traditional natural gas systems are a common alternative and backup that fills the balance of the energy needs. Canada is an early adopter of this technology, and it has implemented ETER as a core component of the Southeast False Creek Neighborhood and Whistler District Energy System.

Process for Thermal Heat Production in Buildings

Common methods for heating buildings include furnaces and boilers.[2] Furnaces use electricity, natural gas, or oil to produce heat that is subsequently distributed via fans and air ducts, and these systems are installed in individual homes. Boilers are also installed in each home and typically use oil or natural gas to heat water. The water is then pumped into pipes which circulate throughout the house to provide heat.

District energy consolidates local thermal heating and cooling systems into a centralized location. Although the concept dates back thousands of years to ancient Rome, widespread implementation is limited in the U.S.[3] An Energy Information Administration (EIA) report in 2018 documented 660 systems in the U.S. in 2012 that served 5.5 billion square feet with heating capacity. District heating and cooling systems allow for the utilization of alternative fuel sources in energy production - sources that would otherwise be impractical for use in individual properties. This diverse array of fuels available, including renewables and clean technology, increases reliability, decreases emissions, and lowers capital and operating costs for buildings.[4]

As illustrated in *Figure 3*, district energy systems send heat from a centralized utility to a building. Each building must install an energy transfer station, which can use the supplied thermal energy for hot water or space heat. ETER is one of the renewable energy sources that can contribute to the production of the centralized thermal energy, although natural gas is the dominating source in these systems. According to *Table 1*, natural gas comprises 80.5% of all fuel sources for U.S. district energy plants that produce Non-CHP Heating.

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[2] Smarter House (2015).
[3] Tredinnick (2013).
[4] EIA (2018).

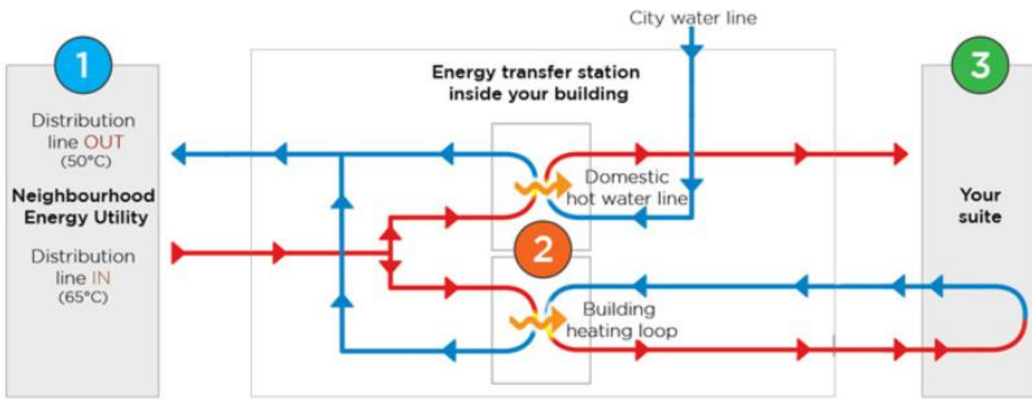

Figure 3. District Energy Layout with a Transfer Station for Heating.[5]

District energy can struggle to remain competitive with traditional furnace and boiler alternatives that use low-cost natural gas. District energy is more competitive in scalability, leading to increased usage in high-density, urban, and compact areas. Within the context of IAWWTF, the feasibility of generating economically sensible, low-carbon heat energy using ETER is studied. Outside of usage for plant operations, which is studied, this thermal energy could be used for heating in a district energy setup for the nearby City Harbor Development.

Table 1. Sources Used in U.S. District Energy Systems: Non-CHP Heating Plants[6]

Fuel Source	Energy Usage (MMBtu)	Percentage of Total
Coal	58,998,023	12.8%
Electricity	0	0%
Natural Gas	372,251,735	80.5%
Oil	11,160,227	2.4%
Other (Biomass)	19,729,303	4.3%
Total	462,139,288	100.0%

Comparable District Systems in Canada

Canada has been a leading adopter of ETER in its energy districts, using this technology as the main provider of space heat and hot water for compact areas of development. Two developments that are explored in this report are the Southeast False Creek Energy District in Vancouver and the nearby Whistler Energy District. While slightly larger than the proposed City Harbor development in Ithaca, these projects provide insight into ETER implementation in contexts

[5] City of Vancouver (2019).
[6] EIA (2018).

outside of a water treatment plant. For the purposes of the market analysis, the focus is on the total energy produced, amount of CO_2 reduced, the percentage of energy derived from wastewater heat recovery, the customers served, and the resulting electricity rates for consumers.

The Southeast False Creek (SEFC) district was most recently redeveloped for the 2010 Winter Olympics hosted in Vancouver. The site was repurposed from an industrial to residential use for the purpose of hosting athletes in the Olympic Village. Originally completed in 2010, the existing plant capacity is 27 MW, which produces 46,000 MWh of energy for 5.2 million square feet spread across 32 buildings[7]. When the expansion of the system is complete, it will serve 6.0 million square feet of residential and mixed-use property and provide 63,000 MWh of energy per year at a total capital cost of $40.3 million ($2010 USD)[8].

Approximately 70% of the annual energy needs in SEFC are met using ETER, reducing building heating pollution by 60%. Natural gas fills the balance of the demand at peak loads, and the combination of the sources saved 3,500 tons of CO_2 in 2017.[9] The Vancouver City Council sets rates for the SEFC district, imposing fixed and variable charges in an attempt to encourage conversation in energy use. This information is summarized with the Whistler Energy District in *Table 2*.

The Whistler District Energy System handles energy needs for the Cheakamus Crossing Neighborhood. This system was also constructed in 2010 for an Athlete's Village as part of the Vancouver Winter Olympics. After the Olympics, the development transitioned to a mixture of affordable and market-priced housing. The total capital cost was $3.9 million ($2010 USD), and the system currently serves more than 500 residential units.[10]

The system was originally designed to serve up to 2,200 residents over 600 buildings consisting of a total of 910,000 square feet. In their calculations, the Whistler Energy Study Program uses 26,500 kWh of energy consumption per year for the average house, implying a current capacity of 13,250 MWh and potential capacity of 15,900 MWh. The District Energy System currently reduces CO_2 output by 1,320 tons relative to the all-natural gas alternative. Cheakamus Crossing sets fixed rates per square footage of floor area to recover operating costs and replacement reserves.

In a 2017 internal study of the system, the report estimated an average thermal energy cost of $0.063/kWh USD relative to $0.09/kWh USD for typical alternatives. This corresponds to a 2018 cost of thermal energy equal to $0.064/kWh for the system, assuming a 1.87% inflation rate in Canada in 2017.[11]

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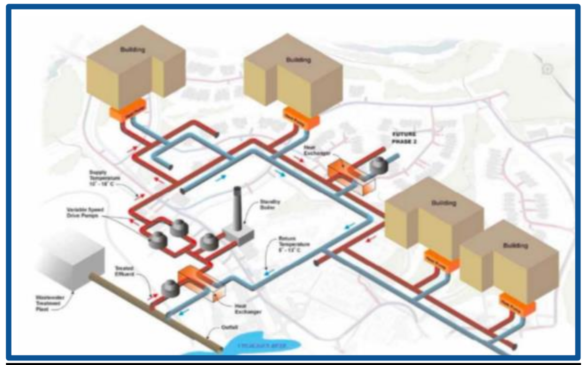
[7] International District Energy Association (2018).
[8] Conversion uses the average spot exchange rate in January 2010.
[9] City of Vancouver (2019).
[10] Whistler Infrastructure Services (2017).
[11] Triami Media BV (2019).

***Table 2*. Comparable District Energy Applications Using ETER**

Southeast False Creek	Whistler Energy District
	
Location: Vancouver, Canada **Constructed**: 2010 **Total Capital Cost**: $40.3 million USD ($2010) **2017 Capacity**: 46,000 MWh **2017 CO_2 Reduced**: 3,500 tons **ETER Usage**: 70% **Net Effective Rate (2018)**: $83.4/MWh USD[12]	**Location**: Vancouver, Canada **Constructed**: 2010 **Total Capital Cost**: $3.9 million USD ($2010) **2017 Capacity**: 13,250 MWh **2017 CO_2 Reduced**: 1,320 tons **ETER Usage**: 50-90% **Net Effective Rate (2018)**: $64.2/MWh USD

Single Building Application: Kiheung Respia WWTP, Korea

There are other international cases of ETER in use that document its environmental impact and heating or cooling demand in districts, which are useful for analyzing IAWWTF's situation.

The design capacity of the Kiheung Respia WWTP in Korea is 7.93 million gallons per day (MGD). Among the three green energy resources considered in this study, two involve electrical energy production (solar PVs and a small hydropower system), and one, the effluent heat, involves thermal energy production using a heat pump. The thermal energy production is calculated manually according to site-specific conditions and heat pump specifications. The green energy production, potential reduction in GHG emissions, and economic viability of the proposed technologies are also estimated.

To extract and transport the heat from the heat source to the heat sink, the heat pump uses some amount of external energy (typically electricity) to accomplish the desired transfer, and the power source is primarily used to drive the vapor compression cycle for heating or cooling purposes. For each kW of electricity used in the heat pump, approximately 4 kW of heat are transferred to the heat recovery system.

An existing nearby three-story administration building, the target building for the heat pump application, was previously equipped with a cooling system running at 65.5 kW and a heating system running at 74.6 kW. An 87.9 kW heat pump with a 25-kW compressor was implemented

[12] City of Vancouver assumes a typical building profile using 10.1 kWh per square foot.

to match the system's capacity. The net energy production of the heat recovery system is calculated by subtracting the input energy from the produced thermal energy. In addition, the produced thermal energy is converted to an electrical energy unit (MWh) to estimate the energy independence of the WWTP.

***Table 3*. Kiheung Respia WWTP Statistics, Korea**	
Environmental Analysis	
Green Energy Production and Savings (MWh/yr)	276
Energy Independence	3.65%
CO_2 Emission Reduction per Year (Tons)	130
Economic Analysis and Savings	
Capacity (kW)	87.9
Installation Cost ($USD/kW)	1,978
Capital Cost ($USD)	173,913
Operating Cost ($USD/yr)	870
Net Effective Rate ($USD/MWh)	100
Annual Electricity Sold ($USD/yr)	26,496
Payback Period (years)	6.8

As a single energy source, the ETER appears to be the most influential factor affecting overall energy independence, which varies according to the number of operational hours of the heating and cooling system.

Municipal wastewater demonstrates substantial thermal energy potential with this project. However, insufficient demand for the recovered heat from the WWTPs in the spring and fall seasons places a constraint on the installation of recovery systems for these thermal reserves. In this case, the recovered surplus heat could be fed into aerobic digesters, which require a constant temperature throughout the year, or supplied to local communities.

An Example of Competitive Alternatives: Freistadt WWTP, Austria

The Freistadt WWTP can be considered as a facility within settlement areas. Current land use in the vicinity of the plant primarily encompasses commercial areas. In addition, a regional hospital is located in the surroundings of the site, and additional commercial areas are being developed at a distance of about 1.5 km from the site as part of a new expressway. Therefore, based on the spatial context, Freistadt shows high potential for thermal surplus energy utilization from the wastewater of existing and future energy consumers.

Based on sector-specific energy indices derived from energy analyses and census data on local units of employment, the heating demand for the regarded business locations can be estimated, amounting to 4,300 MWh_{th}/a for space heating and 4,757 MWh_{th}/a for process energy including drying, process water, and heat up to a temperature level of 100°C (212°F).

The minimum heat price to supply external consumers with heating energy depends on the demand level. The minimum price for supplying heat is, however, 5% lower than the current district heating price in the area of about $64.8/MWh (USD). This heat price of $61.4/MWh (USD) results from the investment and operating cost of a new installed Combined Heat and Power (CHP) plant as well as several new heat pumps and required heat grid. Additionally, around 80% of the used electricity has to be imported, resulting in an overall cost of approximately $261,000/yr. These costs are facing a nearly equivalent annual revenue due to the fact that at $61.4/MWh (USD), the Process Network Synthesis (PNS) calculations, which are used to optimize material and energy flow systems, generate minimal economic benefit.

If process heat is considered, the demand doubles. The increased and more consistent demand over the course of a year decreases the unit costs of production, and a resulting price 21% lower than the prevailing heating cost in the region allows for a sufficient supply of external consumers. At this price, however, only 89% of the 9,057 MWh_{th}/a can be covered with the applied heating technologies as the demand is highest in winter and cannot be met completely. To meet all demand year-round, larger facilities are necessary, resulting in higher prices for consumers due to increased investment requirements and electricity imports.

Table 1
External heat demand and supply from the case study WWTP.

	External demand [MWh_{th}/a]	Minimum price [€/MWh]	Minimum price relative to current price per MWh_{th} [%]
Heating	4300	54	−5
Heating incl. process energy	9057	45	−21

Figure 4. External Heat and Supply from the Case Study of the Freistadt WWTP.[13]

Next, the carbon footprint of the electricity required to run the heat pump is compared to solar and natural gas scenarios. The heat pump driven by the EU mix generates roughly the same ecological footprint as thermal heat produced using natural gas. An ecologically friendlier option is to use heat pumps with an average Austrian electricity mix, resulting in a 52% carbon footprint

[13] Kollmann et. al. (2016).

reduction compared to natural gas, or better yet, heat generated from solar heat collectors, which results in a 66.8% reduction.

By far, the most sustainable option for producing the heat demand of 9,057 MWh_{th}/a in the case study is the scenario involving a wastewater heat pump that derives electricity exclusively from renewable resources. This results in an ecological footprint reduction of almost 99% compared to the business-as-usual scenario run by natural gas.

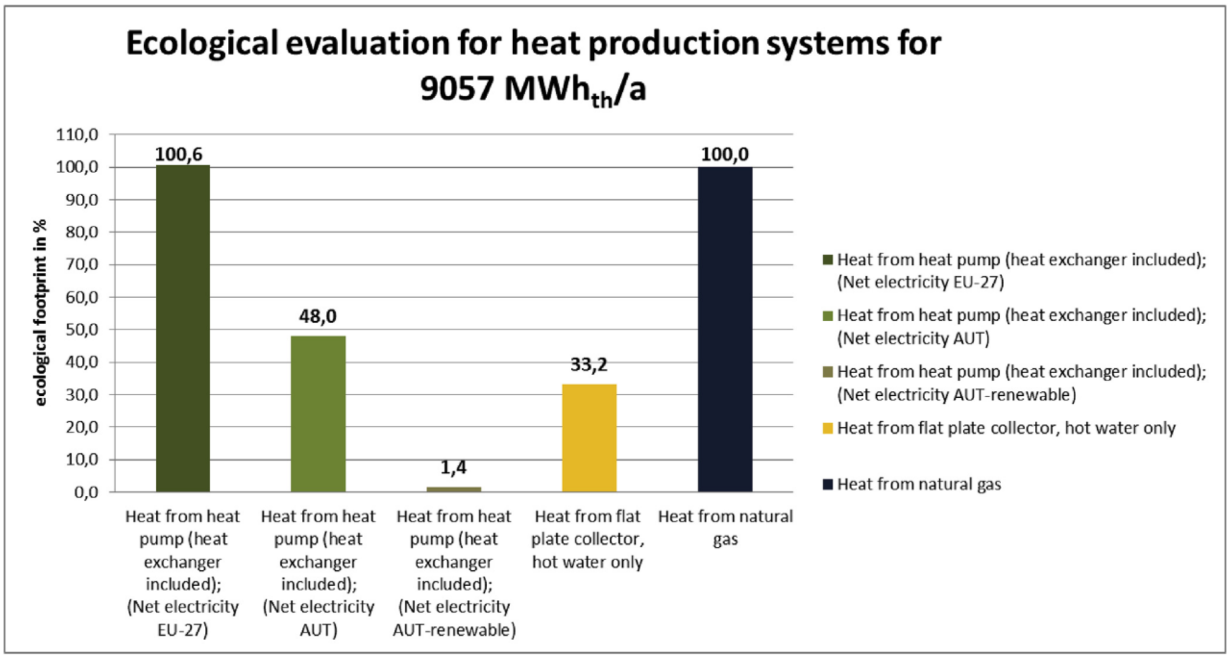


Figure 5. Ecological Evaluation of the Heat Production System in Freistadt WWTP.[14]

Building Demand: Xi'an Urban Wastewater Source Heat Pump (WWSHP) System

Xi'an No. 4 Wastewater Treatment Plant in China was adopted as a pilot project. As part of the project, surrounding buildings were simulated and calculated. Using the operating data including the effluent temperature, flow rate, and water quality as shown in *Figure 6*, the type of WWSHP unit can be designed.

Since the maximum water treatment capacity of this plant is 2×10^5–4×10^5 m^3/d (7.1-14.1 million ft^3/d), the minimum quantity of wastewater used for this WWSHP system can reach 7,500 m^3/h (264,900 ft^3/h), which is calculated by adopting the seasonal adjustment coefficient as 0.9.

In this study, buildings named "X" use the treated wastewater effluent from No. 4 plant as a heat source. "X" buildings are located about 2.5 km (1.55 mi) southeast of No. 4 plant. The building types are residential and commercial. As shown in *Figure 6*, the total area is 530,000 m^2 (18.7

[14] Kollmann et. al. (2016).

million ft^3), with 444,000 m^2 (4.8 million ft^3) for residential heating and 86,000 m^2 (926,000 ft^3) for commercial air-conditioning. A central air conditioning system, which adopts the WWSHP unit as a heating and cooling source, is used for cooling and heating in commercial zones.

TABLE II. GENERAL CALCULATION OF COOLING LOAD AND HEATING LOAD OF "X" BUILDINGS

Table Name	Total Area ($\times 10^4$ m^2)	Heating Heat Index (W/m^2)	Air-conditioning Heat Index (W/m^2)	Heating Heat Load (kW)	Air-conditioning Heat Load (kW)	Air-conditioning Cold Index (W/m^2)	Cooling Load (kW)	Total Heat Load in Winter (kW)	Total Cooling Load in Summer (kW)
Dwelling	44.4	55	-	21978	-	-	-	27378	9720
Commercial	8.6	-	100	-	5400	180	9720		

Figure 6. General Calculation of Cooling and Heating Load of "X" Buildings in Xi'an WWSHP.[15]

Local Application: ETER Prospect at City Harbor

The Ithaca City Harbor development, scheduled for construction in 2019, will be Ithaca's only waterfront neighborhood. The development includes upscale apartments, restaurant space, the Guthrie Clinic, and possibly more mixed-use areas. City Harbor will house three waterfront structures consisting of of 80 units[16]. There will be parking on the ground level and four floors of apartments. In addition, a building facing the Cascadilla Creek called "The Point" will have hospitality and residential uses including a waterfront restaurant. The Guthrie Clinic will be located away from the shoreline in a three story, 60,000 square-foot building. [17]

Figure 7. Revised Sketch Plan of Ithaca City Harbor.

There appears to be tremendous potential for supplying heat for City Harbor using an ETER system at IAWWTF. With numerous residential spaces, recreational spaces, and medical spaces, ETER would be an excellent addition to City Harbor's vision of a "better way forward". The system

[15] Yaxiu, Huqiu, Yu, and Huanjuan (2011).
[16] City Harbor (2019).
[17] O'Connor and Crandall (2018).

could also assist with cooling during summers. This initiative would be a one-of-a-kind, a modern residential space promoting renewable energy and significantly reducing the emission of greenhouse gases through traditional sources of heating. Furthermore, City Harbor is located very close to the IAWWTF, which would simplify energy transport and reduce losses.

City Harbor is currently designed for a mixture of upscale and affordable housing, and a feasibility study of adjustments in utility and heating costs is recommended in order to obtain an accurate estimate of the added costs or benefits for the residents if ETER is utilized.

Environmental Scope of ETER and Alternative Uses

A major benefit of recycling energy from IAWWTF using ETER is the corresponding reduction in greenhouse gas (GHG) emissions. Although GHG itself is not harmful to the environment, the large amount of anthropogenic GHG emissions today is the primary cause of global warming. Hence, the question “How much CO_2 can plants offset?” needs to be addressed.

Since minimal data is available with regards to the amount of GHG emissions IAWWTF can reduce, other plants that are similar to Ithaca’s are examined. Several examples that meet this criterion include the Green Bay, Wisconsin Metropolitan Sewerage District, the old-age home in Hofmatt, Switzerland, and the University of Burgundy in France.

Green Bay, Wisconsin

The Green Bay, Wisconsin Metropolitan Sewerage District has two treatment plants that together serve more than 217,000 residents. One of the treatment plants has installed new energy-efficient blowers in its first-stage aeration system, reducing electricity consumption by 50 percent and saving 2,144,000 kWh/year - enough energy to power 126 homes - and avoiding nearly 1,480 metric tons of CO_2 emissions.

Hofmatt, Switzerland

In the old-age home Hofmatt in Switzerland, residents have decided to use the in-house wastewater flow to recover energy for heating purposes and service water. The use of wastewater at the source offers potential for greater efficiencies. The daily per capita production of wastewater is 130 L (34.3 gallons) on average, and the water has a temperature of 23-25°C. When cooled by 15°C, approximately 2.26 kWh energy can be recovered per day and per capita. With a permissible annual energy demand of 5.1 kWh/ft^2 according to KfW85 and an assumption of 170 heating days, this amount of energy is sufficient to heat approximately 75.3 ft^2 of living space at 100 percent duty.

Figure 8. Green Bay, Wisconsin Metropolitan Sewerage District.[18]

Figure 9. Hoffmatt, Switzerland Old-age Home.[19]

[18] Village of Bellevue (2019).
[19] Alp' Vieux Bois (2019).

University of Burgundy, France

Another example is the University of Burgundy in Dijon, France. The University enrolls 27,000 students every year. To heat the buildings on the 115-hectare campus, the university has opted for a highly ecological solution by reusing the otherwise dumped energy of the new data centre cooling system. As the heating and cooling loads are used simultaneously, a high-temperature heat pump supplied by Ochsner fulfils both functions: cooling the data centre, heating the buildings in winter, and producing hot water in the summer for the kitchens of the university restaurant, among other users. With a heating capacity of 420 kW and a cooling capacity of 255 kW, the heat pump saves 117 tons of CO_2 each year. With a flow temperature of 90°C (194°F) and simultaneous use of the cooling and heating functions, an integrated total COP of 4.2 is obtained.

***Table 4*. Technical Details of the Heating and Cooling System at Burgundy[20]**	
Heating Capacity	420 kW
COP	4.2
Refrigerant	R134a + OKO1
Heating Source	Water
Supplied Temperature	90°C

The reduction of primary energy consumption and carbon dioxide emissions and the enhanced security in water and heat supply are feasible outcomes of a proposed network. In future studies, it is recommended that teams examine the reliability of low or high temperature water sources in producing thermal energy.

Ithaca Wastewater Treatment Plant Overview and Lifecycle Analysis

From the previous examples and sections on energy districts, there are clear indications of the potential to use ETER in IAWWTF to recycle energy. Although the question "How much CO_2 can plants offset?" cannot be directly answered, these figures provide a rough estimate of the reduction in GHG emissions that ETER or other clean energy systems can achieve. To understand how IAWWTF's use of ETER can reduce GHG emissions, an analysis of the plant's electricity and heating sources and uses is conducted in this report's economic section.

It is also imperative to gain an understanding of IAWWTF's existing operations. The processes can be divided up into three major types: physical, biological and chemical.[21]

[20] University of Burgundy (2019).
[21] Lozano (2018).

IAWWTF begins with physical processes to remove solids in the wastewater. First, large solids are removed by bar screens. The removed solids are landfilled. Next, the treated water is sent to primary settling tanks to remove more solids. Heavy solids settle while lighter ones float, removing approximately 30% of the incoming organic load. The settled solids are de-gritted and dewatered before going to the digester.

However, the physical processes are unable to treat the water and remove harmful microorganisms and microscopic particles in the water. This requires the use of an activated sludge process in which the clarified primary wastewater is fed to aerobic microorganisms under constant aeration. The microorganisms in the aeration tanks agglomerate and assimilate the organics in the wastewater. The formed “floc” particles are clumps of microbes and food. Then, the secondary clarifiers remove the floc by gravity settling. To keep a constant ratio between the amount of biomass (organisms) in the aeration tanks and the amount of incoming organic loading (food), much of the activated sludge that settles in the secondary clarifiers is returned to the aeration tanks. The excess activated sludge is removed to the thickeners for further treatment.

Finally, the wastewater is sent through tertiary treatment. The tertiary treatment primarily utilizes chemical processes to remove the excess microorganisms and micro-particles. Using 3 additives, including polymer, ferric chloride and engineered sand, additional suspended solids are clumped together in larger particles that are heavy enough to settle and be removed. This system is optimized for phosphorus removal, removing roughly 80% of the remaining dissolved phosphorus. Half of the other remaining conventional pollutants are also removed. Waste sludge from this system goes to the thickeners.

Excess water is removed from all the waste sludges in the thickeners and sludges from the previously described processes. The thickened sludge is pumped to the primary digester for anaerobic digestion to reduce the biomass. The biomass is digested for 28 days at 98°F, and a secondary digester is used for overflow. The digesters stabilize the sludge, after which it is dewatered with chemical polymer and belt press. 6,000-12,000 lbs/day of semi-dried cake is created and subsequently removed to a landfill.

Pathogen disinfection using chlorine bleach (sodium hypochlorite) occurs after tertiary treatment. After thorough mixing, sulfur dioxide removes remaining chlorine. Finally, the clean effluent can be discharged to Cayuga Lake.

Additionally, anaerobic digestion biogas generates methane. Although an energy upgrade is planned, this biogas currently generates 25-30% of the total energy (heat and electricity combined) requirements of the IAWWTF. As the energy performance upgrades are completed, the total external energy requirements of the plant will decrease while the amount of energy produced from biogas will increase. These improvements will result in 60% of IAWWTF’s energy requirements met through the use of biogas.

Given these circumstances, IAWWTF can help transform Tompkins County into a place where the community's energy needs are met without production of GHG from fossil fuels. This is a particularly opportune moment since Tompkins County is dedicated to reducing GHG emissions by a minimum of 80% of 2008 levels by 2050 and decreasing its reliance on various sectors of fossil fuels for energy production. Moreover, the government hopes that the energy efficiency of all components of the community will improve and that the use of local and regional renewable energy sources and technologies will increase. Hence, IAWWTF could be a key renewable energy instigator by implementing ETER.

Analysis of ETER Applications to IAWWTF

Research into existing uses of ETER at water treatment facilities worldwide has provided insight into options for applying that technology locally at IAWWTF. The technical analysis of this report demonstrates the feasibility of an ETER project at IAWWTF, estimates the size of the system, and provides the resulting energy output. The economic analysis examines capital and operating costs for ETER, and it describes a model developed for this report that assesses how ETER would be integrated into the plant's energy mix and new sludge drying system. Finally, the environmental analysis tracks the emissions of various energy mix scenarios at IAWWTF and quantifies the reduction in CO_2 resulting from burning fossil fuels. These results are synthesized to provide recommendations and conclusions for IAWWTF's energy plans.

Technical Dimension and System Overview

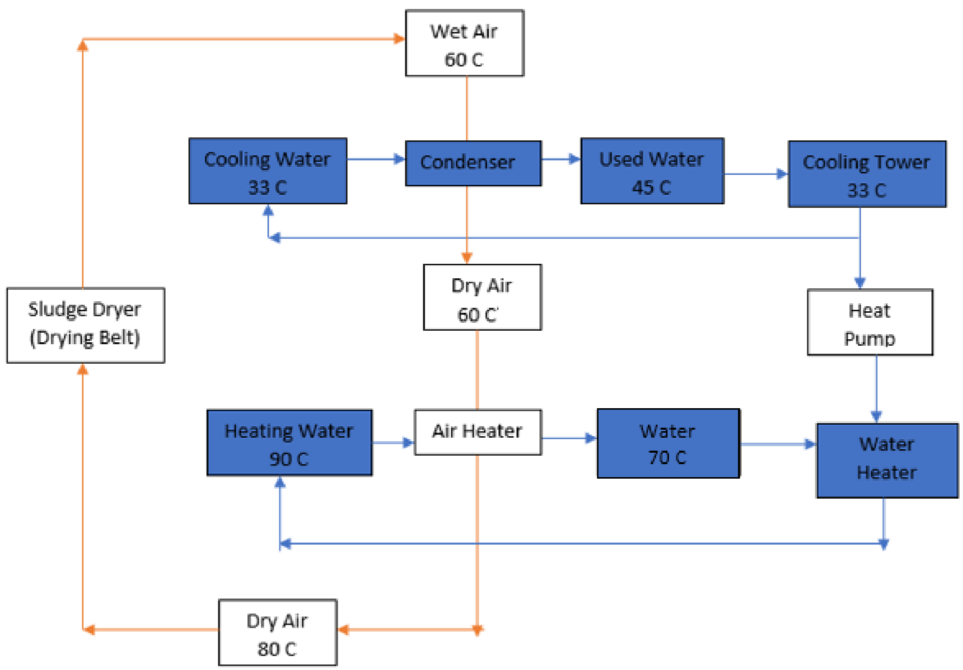


Figure 10. Basic ETER System Outline for IAWWTF.[22]

Figure 10 depicts the basic ETER system technical structure as it could be applied to IAWWTF. The blue system represents the water heating and cooling from the heat pump and cooling tower. The orange system is the air system, which would dry the sludge and potentially incorporate a heat exchanger. The sludge arrives with a high percentage of moisture and water; using the hot, dry air, the sludge can be dried to a significantly lower percentage of water.

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[22] Note: Depending on the design, the implementation of the heat pump shown may avoid the need for a cooling tower.

The water is recycled to absorb the moisture that the air has received from drying the sludge. Next, the water moves into the heat pump where it is heated. Finally, using a heat exchanger, the water transfers heat to the air to raise its temperature for drying the sludge.

The efficiency of the heat pump and heat exchanger must be considered to ensure that the temperature lift is attainable. The following section outlines the assumptions of the ETER system at IAWWTF using a Coefficient of Performance (COP) of 4, a temperature lift of 5 °F, and a percent of sewage extracted of 15%. The minimum amount of water needed is calculated, but there will be additional head and heat losses that need to be considered.

Sludge Drying System Calculations and Potential Savings

IAWWTF receives anywhere from 10 to 14 tons of liquid sewage and trucked waste for use in the plant's biodigester system[23]. When biogas is released in the system, sludge emerges as a byproduct with a water content of 75%. While IAWWTF currently has a drying system to reduce the total weight of sludge, the plant still pays approximately $250,000 per year to transport the output to a landfill. If IAWWTF could use more heat in its drying system to reduce the sludge water content to 10%, the leftover dried product could be used as fertilizer. With an upgraded sludge drying system, IAWWTF could avoid the landfill fee and explore options to sell or donate the dried sludge to local businesses.

***Table 5*. Sludge Drying Technical Analysis**

Amount of Sludge the Plant Receives	14 tons per day
Amount of Heat Needed to Dry the Sludge	54.32 mmBTU/day
Wastewater Needed to Dry the Sludge using ETER	975,000 gallons per day
Clean Water Needed to Circulate in ETER System	181,000 gallons per day

Only 15% of the heat available from the wastewater is needed to properly dry the sludge. It is likely that more heat could be extracted if desired, and this could be used for the plant's operational heating needs or sold to City Harbor.

In order to calculate the amount of wastewater heat required and the amount of clean water needed in circulation, several assumptions have been developed as outlined in *Table 5*, *Table 6* and *Table 7*.

[23] Lozano (2018).

Table 6. Heat Extraction Parameters	
Sewage Flow	6.5 MGD
Minimum % Extracted	15%
Delta T	5
COP	4

Table 7. Heat Produced and Electricity Used	
Total Flow Diverted	0.975 MGD
Energy from Water	40.61 mmBTU/day
Compressor Input	13.54 mmBTU/day
Total Available Heat	2.26 mmBTU/hr
Required Heat Pump Power	661 kW
Electricity Used per Year	1,445,400 kWh

The COP of the ETER system helps determine the total energy that can be produced given the energy input. Since approximately 54 mmBTU/day is needed to dry the sludge, the input the system needs is about 13.5 mmBTU/day, assuming a COP of 4. The energy input required can then be converted to kWh, which indicates the amount of electricity that is needed to operate the system. For the IAWWTF, it is estimated that 1.44 million kWh are required to run the ETER heat pump year-round. The COP value was determined based on data from similar systems.

Benchmarking Costs and Revenue

Korea Plant Analysis

The ETER system in Kiheung Respia WWTP, Korea, previously described in this report's market analysis, is a revenue-generating system that provides sufficient data to re-create a financial model. This is helpful for benchmarking costs and economic benefits, which can then be used in analyzing ETER at IAWWTF. Assuming the discount rate to be 5% and applicable over a 30-year project lifespan, this case indicated a breakeven that's achieved after 6.79 years of operation. It also suggests that over the course of 30 years, the ETER system could achieve a 14.48% IRR, and the total NPV could be as much as $220,019.

Table 8. Key Statistics for Kiheung Respia Financial Analysis	
Energy Production (MWh/yr)	276
Heat Pump Capacity (kW)	87.925
Installation Cost Per kW (US$/kW)	$1,978
Annual Operating Cost (US$/yr)	$870
System Marginal Price (US$/kWh)	$0.10
Revenue, Year 1 (US$/yr)	$26,496
Financial Assumptions	
Discount Rate	5%
Project Lifetime (yr)	30
Annual Revenue Escalations	0%
Financial Outputs	
Initial Investment Cost (US$)	$173,916
Payback Year (5% Discount Rate)	6.79
IRR (30-year-project)	14.48%
NPV Operating Cash Flows	$393,934
Total NPV	$220,019

The results of this analysis are documented in *Table 8*. In addition, a chart of the cumulative cash flows for the project is shown in *Figure 11* to illustrate the determination of breakeven in between Year 6 and Year 7. Notably, although operating costs are provided for this project, they seem representative of maintenance costs and do not appear to include the cost of electricity for operating the heat pump. The cost of electricity might not be incorporated into the plant's operation cost data because of existing and sufficient on-site electrical energy resources to power the heat pump, thereby eliminating the need for electricity purchases from the grid.

If Kiheung Respia incorporated the cost of electricity in the model and assumed a COP of 4, the demand from the heat pump would be approximately 69 MWh/yr. At a cost of electricity of $0.10/kWh, the additional annual cost would be $6,900. The resulting IRR would decrease to 10.2%, and the payback period would fall between 9 and 10 years. Incorporating electricity costs in the financial analysis of Kiheung Respia appears to maintain the economic feasibility of the plant's ETER project.

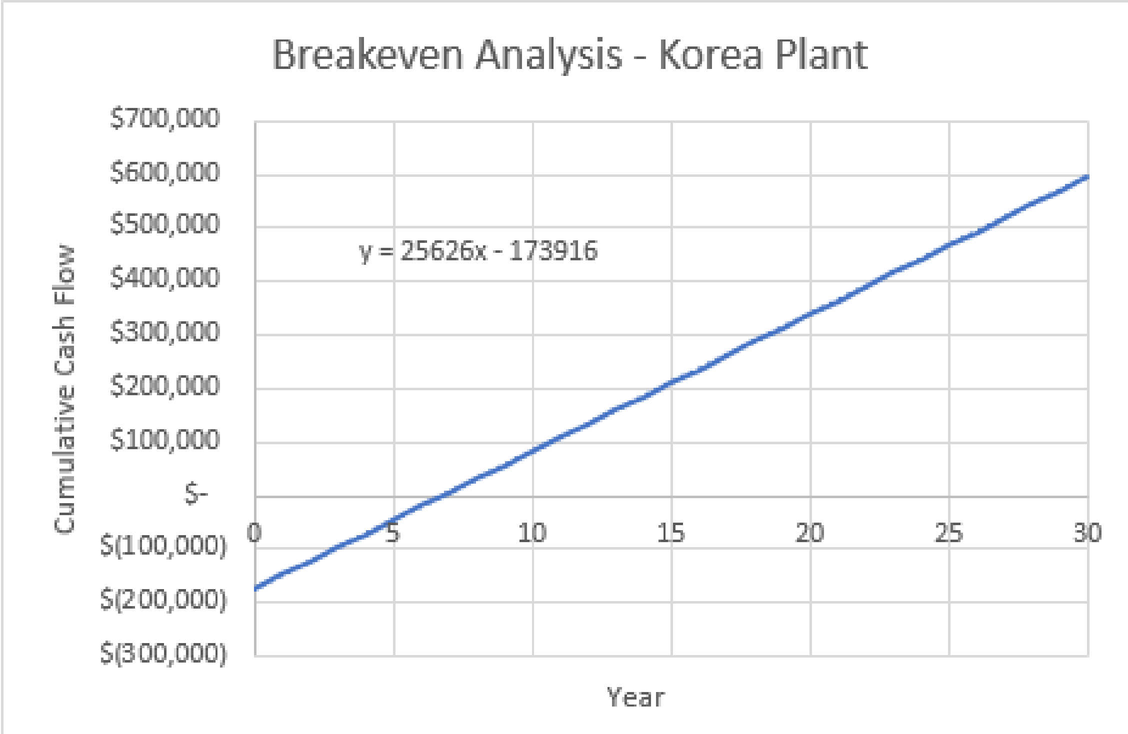

Figure 11. Break Even Analysis for Kiheung Respia.

The Kiheung Respia plant is used to calculate a realistic annual maintenance cost of \$0.0032/kWh, which is the plant-provided Annual Operating Cost number divided by Energy Output as shown in *Figure 12*.

$$Annual\ Maintenance\ Cost\ per\ kWh = \frac{Annual\ Maintenance\ Cost}{Annual\ Energy\ Output} = \frac{\$870}{276\ MWh} = \$0.003152\ per\ kWh$$

Figure 12. Derived Annual Maintenance Cost per kWh.

According to a Fall 2015 Cornell Engineering Management Project[24], the maintenance cost of a similar CHP system is about \$0.01 per kWh. The estimated maintenance cost of the Kiheung Respia ETER system is about one third of the cost of the comparable CHP system, which verifies that the calculated maintenance cost result is realistic.

The Kiheung Respia Plant also provides an opportunity to assess the sensitivity of the results subject to inputs for maintenance costs, installation costs, heat pump installed capacity, and annual revenue escalations. Two sensitivity analyses are performed: installation cost per kW versus annual maintenance cost, and heat pump capacity versus annual revenue escalations. The first sensitivity analysis is detailed in *Figure 13* that follows and demonstrates that reasonable

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[24] Frazier et. al. (2015).

variances in installation cost have greater influences on total project NPV than variances in operating cost.

		Installation Cost per kW				
		$ 1,582	$ 1,780	$ 1,978	$ 2,176	$ 2,374
Operating Cost ($/yr)	$ 522	$ 260,152	$ 242,760	$ 225,368	$ 207,977	$ 190,585
	$ 696	$ 257,477	$ 240,085	$ 222,694	$ 205,302	$ 187,910
	$ 870	$ 254,802	$ 237,410	$ 220,019	$ 202,627	$ 185,236
	$ 1,044	$ 252,127	$ 234,736	$ 217,344	$ 199,952	$ 182,561
	$ 1,218	$ 249,452	$ 232,061	$ 214,669	$ 197,278	$ 179,886

Sensitivity Analysis Parameters: Case 1
1. Operating Cost +/- 40%
2. Installation Cost +/- 20%
3. Table output measures variance in the Total NPV of the project.

Figure 13. Sensitivity Analysis of Maintenance Cost and Installation Cost.

Next, the second sensitivity analysis is detailed in *Figure 14*. Although IAWWTF may not use the heat produced by ETER as a revenue-generating source for City Harbor, this analysis demonstrates that small annual increases in the prices for heat sold to customers can dramatically increase the project NPV, from $220,019 in the base case with a 0% escalation to $473,921 with a 4% escalation. Lower installed heat pump capacities tend to result in higher NPVs, likely because this translates into a lower capital cost for the system. Capital costs are penalized heavily in the model because of the time value of money and the 5% discount rate. The more that capital costs can be controlled, the more likely it is that the economic viability of an ETER project will improve.

		Heat Pump Capacity (kW)				
		70.3	79.1	87.9	96.7	105.5
Revenue Escalations	0%	$ 254,802	$ 237,410	$ 220,019	$ 202,627	$ 185,236
	1%	$ 303,316	$ 285,925	$ 268,533	$ 251,141	$ 233,750
	2%	$ 360,537	$ 343,146	$ 325,754	$ 308,362	$ 290,971
	3%	$ 428,267	$ 410,876	$ 393,484	$ 376,093	$ 358,701
	4%	$ 508,704	$ 491,312	$ 473,921	$ 456,529	$ 439,137

Sensitivity Analysis Parameters: Case 2
1. Revenue Escalations ranging between 0% and 4%*
2. Heat Pump Installed Capacity +/- 20%
3. Table output measures variance in the Total NPV of the project.

*Based on 1.46% CAGR from the Montpelier agreement

Figure 14. Sensitivity Analysis of Annual Revenue Escalations and Installed Capacity.

Heat Pump Manufacturer Regression

Many case studies and prices listed on vendor websites show that the total capital cost per kW (the aggregate of heat pump cost and installation cost) changes with heat pump capacity[25]. In order to verify this relationship, data points from an Arcadis study for sewer heat recovery technology installed costs and heat pump capacity are analyzed by building a regression model. When the points are plotted in *Figure 15*, a logarithmic relationship is visually identified. Taking the log of the x-component improves the linear regression and confirms the observed logarithmic relationship between total installation cost and heat pump capacity. This result is shown in *Figure 16*.

According to the logarithmic model parameters documented in *Table 9*, a heat pump capacity of 660 kW per the technical analysis specifications corresponds to a predicted installation cost of $949,000, implying an installation cost of $1,438/kW. Furthermore, within the data provided by the Arcadis memorandum, one type of SHARC heat pump used in international wastewater systems has a capacity of 2,200 mBTU/hr, which equals 645 kW. This capacity is very close to 660 kW and has a total installation cost of $980,000, implying a ratio of $1,519/kW.

A 95% prediction interval for the cost of new heat pump capacities can also be calculated with the regression results in Excel given the standard error, the average of the logarithm of the capacities, and the sum of the squared deviation of each data point. The conclusions from this analysis are displayed in *Table 10*. When the confidence level is 95%, the corresponding t-value is 2.2010, and the prediction interval has a total installation cost lower limit of $1,066.8/kW and an upper limit of $2,297.1/kW for a 660-kW system. This range aligns well with real data and is informative for the sensitivity analyses of the IAWWTF system.

In conclusion, the regression model results and comparable system in the Arcadis memorandum suggest that a total installation cost of $1,500/kW is a reasonable estimate for the capital cost of a 660 kW ETER system. This can be used in the subsequent economic analysis for IAWWTF.

[25] Arcadis and Malcolm Pirnie (2013).

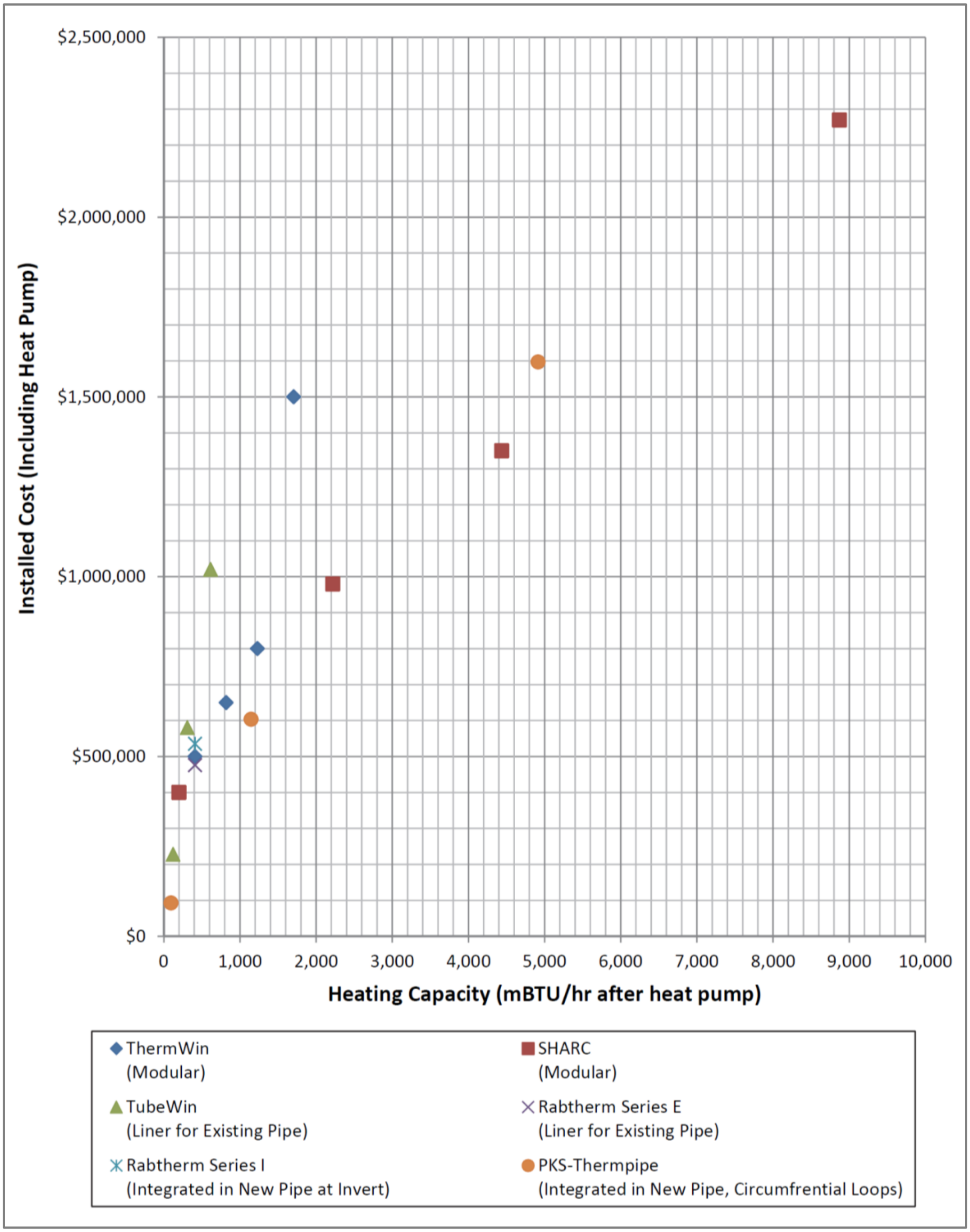

Figure 15. Sewer Heat Recovery Installed Cost Vs. Heating Capacity.[26]

[26] Arcadis and Malcolm Pirnie (2013).

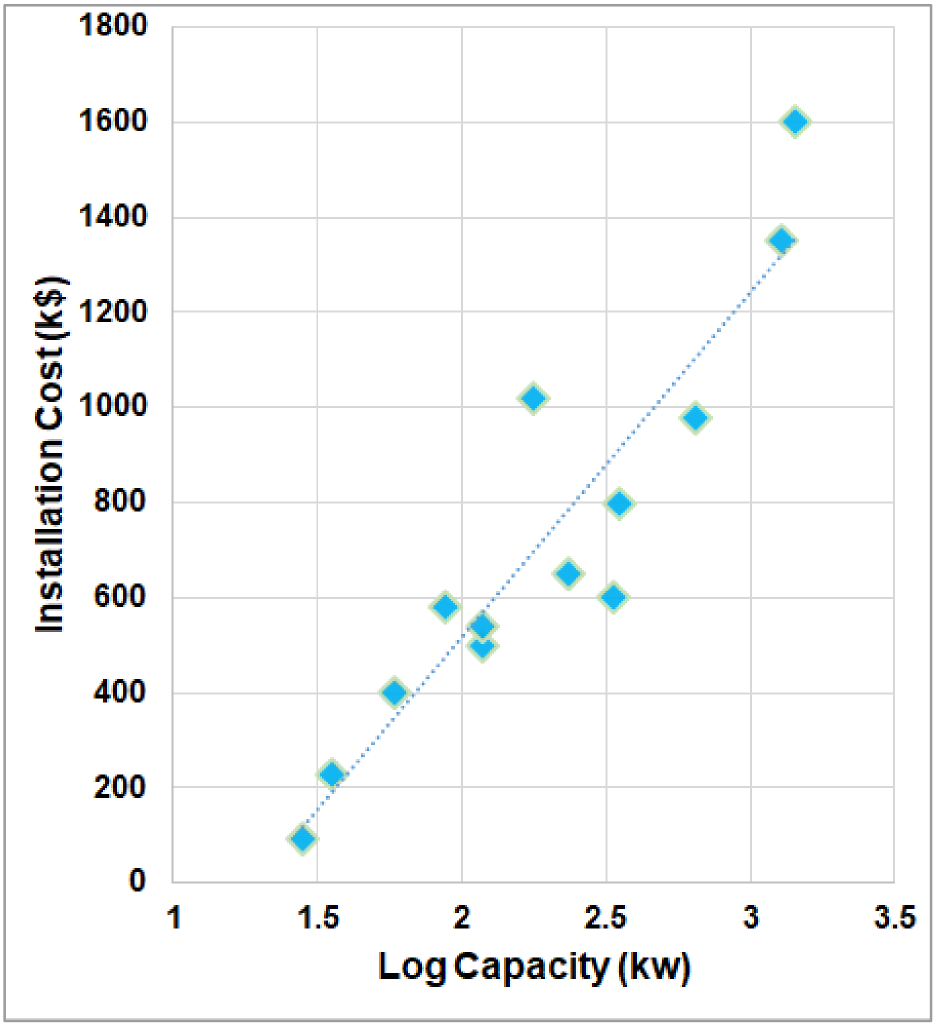

Figure 16. Logarithmic Model of Installation Cost ($000) Vs. Log Capacity (kW).

***Table 9*. Logarithmic Regression Summary**	
Logarithmic Regression Model Coefficients	
Intercept	410.3825
Heat Pump Capacity(kW)	0.8162
Predicted Installation Cost	
Required Capacity (kW)	660
Prediction Installation Cost ($000)	949.04
Prediction Installation Cost ($/kW)	1,437.94

Table 10. 95% Confidence Interval Summary	
Heat Pump Capacity (kW)	660
Prediction Installed Cost ($000)	949.04
t-Value (95%)	2.2010
Predicted Total Installation Cost	
Lower Limit ($000)	704.1
Upper Limit ($000)	1,516.1
Predicted Installation Cost Per kW	
Lower Limit ($/kW)	1,066.8
Upper Limit ($/kW)	2,297.1

Solar Analysis

Operational costs for solar are highly variable and dependent on owner preferences for maintenance, upkeep, and miscellaneous items like property taxes, which do not apply at IAWWTF. According to the National Renewable Energy Laboratory (NREL), the average operational cost for a commercial-scale solar PV system that could be used at IAWWTF equates to about $15/kW per year[27]. This may include expenditures for cleaning the panels, repairs, and insurance. At a capacity factor of 12.1% in Ithaca as derived in the economic analysis section, $15/kW per year translates to a cost of $0.0142/kWh.

The capital cost for solar PV systems has become more predictable in recent years, and the NREL's most recent estimate for commercial-scale arrays amounts to $1,830/kW[28]. Using an estimated installed capacity of 400 kW at IAWWTF, the annual operational costs are estimated to be $6,000 per year while the capital cost of installation amounts to $732,000.

Revenue and Heat Demand from City Harbor

For the purposes of this project, it is assumed that heat produced from the ETER will be used for internal plant purposes before distribution to external stakeholders. Heat produced will first go towards the improved sludge drying system at the plant followed by ongoing operations Lastly, any leftover heat production can be sold to City Harbor.

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[27] NREL (2017).
[28] NREL (2018).

Based on an audit from the Office of the New York State Comptroller, the annual heat demand within IAWWTF from ongoing operations is estimated to be 9,333 mmBTU/yr for space, process, and water heating[29]. The technical analysis in this report demonstrates that additional heat demand from an improved sludge drying system amounts to 19,710 mmBTU/yr. Finally, for City Harbor, the heat demand was approximated using average heat demand per square foot from 40 houses at Ecovillage in Ithaca. Given that the total heating space within City Harbor is about 65,800 square feet, the annual demand is estimated at 1,080 mmBTU/yr. The heating demand discussed in this section is outlined in *Figure 17* below.

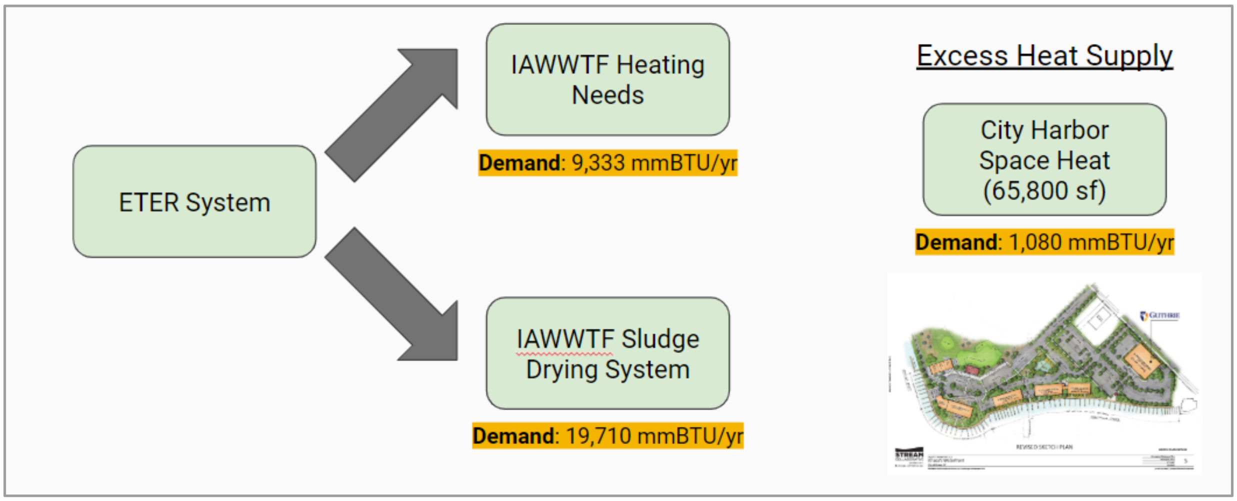

Figure 17. Outline of Heat Demand and ETER Heat Distribution.

The cost of heat supplied to City Harbor is $4.7/MBTUH/month and is based on the Montpelier District Heat Customer Agreement[30]. The conversion to $/mmBTU is shown in *Figure 18* that follows and converts this figure to $6.63/mmBTU. While the size of the ETER system in this report will not generate enough heat to send excess capacity to City Harbor, the maximum potential annual revenue from the sale of heat is $7,160 per year. This offers IAWWTF another alternative for generating savings or revenue from the production of ETER heat.

$$\frac{\$4.77}{MBTUH * month} * \frac{1MBTUH}{0.29307kW} = \frac{\$4.77}{0.29307kW * month}$$

$$Revenue\ from\ Heat = \frac{\$16.276}{kW * month} * \frac{1\ month}{720\ hours} * \frac{1\ kWh}{0.0034905\ mmBTU} = \$6.63/mmBTU$$

Figure 18. Conversion of Montpelier Rate to $/mmBTU.

Economic Analysis

The outputs from the cost and revenue benchmarking analysis provide useful insights for the development of an economic model for IAWWTF's electricity usage and mix over a 30-year

[29] Office of the New York State Comptroller (2016).
[30] City of Montpelier (2012).

project period. Assumptions for the model are documented below followed by the results of the various business scenarios and sensitivity analyses.

Financial Assumptions

In any economic analysis, it is important to outline all assumptions. Key assumptions with the model for IAWWTF include the discount rate, project period, price of electricity purchased from the grid, and price of heat purchased from the grid. These are outlined in *Table 11* that follows.

The discount rate is an assumption based on the cost of capital for IAWWTF, calculated using the most recent financial audit for the plant. IAWWTF frequently utilizes debt financing for energy improvement projects; in 2016, the average cost of debt for these improvements was approximately 2.8% and is derived from the average interest rate expensed in the period[31]. Since a higher discount rate signals higher risk, 5% is selected for this project given that the technology has been tested and proven but not implemented on a large scale worldwide. The team believes that 5% is a conservative assumption for this project and recommends that it be viewed as close to the reasonable upper limit for the discount rate.

***Table 11*. IAWWTF Financial Assumptions**	
Discount Rate	5%
Project Period	30 Years
Cost of Electricity from the Grid	$0.092/kWh
Cost of Supplied Heat from Natural Gas	$7.21/mmBTU

The project period is assumed to be 30 years. This period is selected as a reasonable outlook for expected energy production from new and old systems, and the model considers consistent operational and maintenance expenditures for all energy assets. In addition, the cost of electricity and heat from the grid is annualized from a 3-year average of total energy consumption and expenditures necessary to meet plant needs from January 2013 to December 2015 as documented in the 2016 energy audit from the New York State (NYS) Comptroller[32]. The calculated cost of purchased electricity aligns with expectations, while the cost of heat is likely low due to discounts realized from purchasing heat in large, industrial-scale quantities.

Sources and Uses of Energy

Figure 20 provides a visualization for the allocation of sources and uses of energy throughout IAWWTF. The plant's primary sources are purchased power, purchased natural gas heat, and biogas. The biogas system produces both electricity and heat, and the cost of producing this in

[31] Insero & Co. (2017).
[32] Office of the New York State Comptroller (2016).

total is determined from the NYS audit to be \$0.049/kWh of electricity output. In the model, these costs are allocated proportionally to heat and electricity, with 73% of biogas operational costs attributable to the generated electricity and 27% of operational costs attributable to generated heat. This calculation is shown in *Figure 19*.

$$Electrical\ Proportion\ of\ Biogas\ Operational\ Cost\ = \frac{Electricity\ Produced}{(Heat\ Energy\ +\ Electrical\ Energy)}$$

$$= \frac{1{,}366{,}667\ kWh}{(1{,}767\ mmBTU * 1{,}000{,}000 * 0.000293\ kWh/BTU)} = 73\%$$

Figure 19. Sample Calculation for Electrical Share of Biogas Operational Cost.

The economic model assesses electrical and heat demand for the future by projecting historical data. Compound Annual Growth Rates (CAGR) are computed using available energy consumption data from 2002 and 2003[33] and comparing those benchmarks to near present-day consumption levels documented in the NYS audit. On average, the CAGR for electricity use is 0.34%, while heat consumption decreased over the period. For the purposes of this report, electrical demand for continuing operations over the project period is conservatively estimated to grow 1% annually, while heat demand is assumed to be constant.

The model developed for this report calculates output from several potential on-site energy sources, including the existing biogas system, a solar PV array, and ETER. Using the solar PV array and ETER are decision variables. The balance of the plant's energy needs are filled by purchased power and purchased natural gas. Incorporating an improved sludge drying system is another decision variable that increases the plant's heat consumption and results in annual cost savings, while normal operational demands are kept separate from the decision to use the sludge drying system. If the plant produces heat in excess of its needs, it is assumed that IAWWTF can sell the energy to City Harbor for a preset price of \$6.63/mmBTU[34] as derived in the benchmarking costs section.

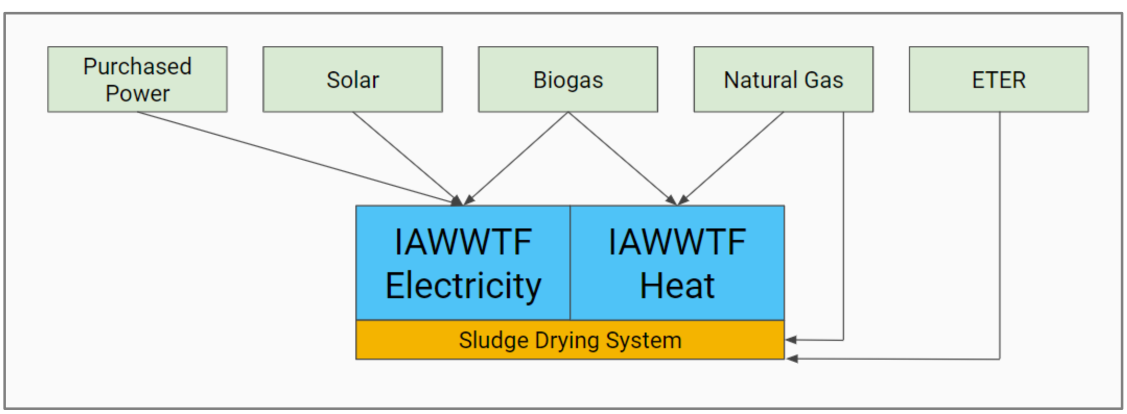

Figure 20. Sources and Uses of Heat in IAWWTF.

[33] Malcolm Pirnie, Inc. (2005).
[34] City of Montpelier (2012).

Summary of Cost of Sources and Revenue

The costs of sources are based on estimates obtained in the benchmarking costs section of this report. These are summarized along with revenue and sludge drying assumptions in *Table 12*. All values shown in this table are considered expected values, and a sensitivity analysis is performed later in this report to assess the impact of variability in key model components.

***Table 12*. Model Cost Assumptions**	
Solar PV Array	
Capital Cost	$1,830/kW
Annual Operational Cost	$15/kW
Maximum Installed Capacity	400 kW
Estimated Annual Electricity Output, 400 kW	425,646 kWh
Implied Capacity Factor	12.1%
ETER	
Capital Cost	$1,500/kW
Annual Operational Cost per kWh Used	$0.0032/kWh
System Size	660 kW
Electricity Used per Year (90% Utilization)[35]	1,300,860
Heat Output per Year (90% Utilization)	17,787 mmBTU
Additional Revenue and Savings	
Heat Sales to City Harbor	$6.63/mmBTU
Sludge Drying Savings per Year	$250,000

In the scenario analysis that is documented later in this report, several financial metrics are reported. First, the Net Present Value (NPV) of the project reports the present value of all project expenditures over the 30-year period and accounts for capital expenditures, operational and

[35] 100% utilization would imply that the ETER system is used for all hours of a given year. A 90% utilization rate is assumed to account for downtime due to maintenance.

maintenance costs, all purchased energy, revenue from the sale of heat to City Harbor, and savings realized from the improved sludge drying system. The Levelized Cost of Electricity (LCOE) is determined using the formula displayed in *Figure 21*, and it represents the present value of the cost to supply electricity divided by the present value of the electricity supplied over the project period. Similarly, the Levelized Cost of Heat (LCOH) is shown in *Figure 22*, representing the present value of heat costs divided by the present value of heat supplied.

$$LCOE = \frac{\sum_{t=0}^{30} \frac{I_t + O_t + G_t}{(1+r)^t}}{\sum_{t=0}^{30} \frac{E_t}{(1+r)^t}}$$

$$I_t = Capital\ Expenditures\ in\ Year\ t$$
$$O_t = Operational\ and\ Maintenance\ Expenditures\ in\ Year\ t$$
$$G_t = Cost\ of\ Grid\ Electricity\ in\ Year\ t$$
$$E_t = Total\ Electricity\ Supplied\ in\ Year\ t$$
$$r = Discount\ Rate\ (5\%)$$

Figure 21. Levelized Cost of Electricity Calculation.

$$LCOH = \frac{\sum_{t=0}^{30} \frac{I_t + O_t + G_t}{(1+r)^t}}{\sum_{t=0}^{30} \frac{H_t}{(1+r)^t}}$$

$$I_t = Capital\ Expenditures\ in\ Year\ t$$
$$O_t = Operational\ and\ Maintenance\ Expenditures\ in\ Year\ t$$
$$G_t = Cost\ of\ Grid\ Heat\ in\ Year\ t$$
$$H_t = Total\ Heat\ Supplied\ in\ Year\ t$$
$$r = Discount\ Rate\ (5\%)$$

Figure 22. Levelized Cost of Heat Calculation.

It is important to note that the ETER system requires electrical energy to maintain operations. However, this electrical energy required for ETER and the corresponding cost of that electricity should not be included in the LCOE calculation, since the output of the ETER system is heat. Consequently, the cost of electricity used to generate heat from ETER is considered an operational expense for the LCOH calculation.

When considering capital expenditures for the Solar PV array and ETER, it is assumed that all capital expenditures for ETER are expensed in Year 0 (2019) in the model, with Year 1 (2020) serving as the first year of heat production and incurred operating expenses. An installed solar array is assumed to be phased in over Year 0 and Year 1, with operational costs and electrical output allocated proportionally to the installed capacity in each year.

In addition, it is assumed that IAWWTF will not have government grants available to assist with the cost of an ETER project. However, the project may be eligible for grants through the New York

State Energy Research and Development Authority (NYSERDA)[36]. Programs of interest to IAWWTF may include the Clean Energy Communities Program or Strategic Energy Management Pilot. Recently, IAWWTF received a grant in 2016 from NYSERDA for a feasibility study.

Lastly, IAWWTF is a government facility, meaning that tax expenditures and incentives are not considered in this report. If private entities want to install and operate an ETER system, it is recommended that they consider taxes and the tax benefits of depreciation in an economic analysis. Estimates for the depreciable life of ETER and solar energy systems range between 20 and 25 years and employ a straight-line depreciation method[37] in accordance with the Governmental Accounting Standards Board (GASB) Statement 34.

Scenario Analysis

Assessing the economic viability of ETER and clean energy systems at IAWWTF requires the consideration of multiple scenarios. Using the assumptions outlined previously, five scenarios are developed to address the goals of this report.

1. **Business-As-Usual**: This assumes no solar PV array or ETER is installed at IAWWTF and provides a base case for comparison with scenarios that use these systems.
2. **Max Solar Only:** In this case, a 400 kW solar PV array is installed at IAWWTF with no ETER utilized.
3. **Sludge Drying System Only**: This scenario assumes that IAWWTF increases its heat consumption to realize the $250,000 cost savings from fully drying the sludge. However, this business case does not utilize ETER or solar, meaning that all additional heat demand needs to come from natural gas.
4. **Sludge Drying with ETER Only**: This assumes utilization of ETER to provide a relatively clean heat source for the sludge drying system.
5. **Sludge Drying with ETER and Max Solar**: The fifth scenario combines all possible new energy sources within the scope of this project.

In all scenarios, the electricity demand from normal operations is estimated to be 3,630,000 kWh in Year 0, implying a present value of all electricity supplied equivalent to 66,703,023 kWh. Without increasing the heat use of the sludge drying system, the heat demand for the plant in Year 0 is 9,333 mmBTU. This implies that the present value of all heat supplied is equivalent to 152,806 mmBTU. Fully drying the sludge nearly triples the present value of all heat consumption at IAWWTF to 455,800 mmBTU.

To illustrate the influence of the various electrical and heat sources in the context of total consumption, *Figure 23* and *Figure 24* illustrate breakdowns of the energy provided from each source in Year 1. *Figure 23* demonstrates that maximizing the capacity of the installed solar array increases the proportion of electricity provided by solar to 10%. *Figure 24* shows that using ETER

[36] NYSERDA (2019).
[37] Louisiana DOA (2001).

significantly shifts the proportion of total heat provided by this energy source. This makes sense because of the large increase in sludge drying heat demand associated with the use of ETER. The size of the ETER system as determined in the technical analysis satisfies the majority of the new sludge drying demand.

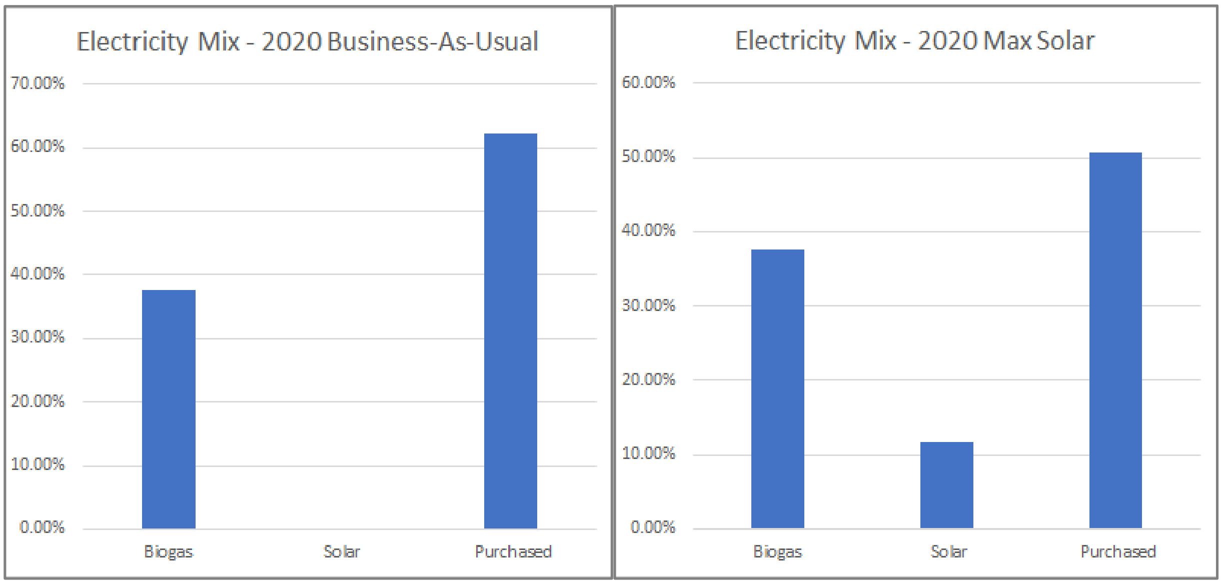

Figure 23. Electricity Mix Comparison between Business-As-Usual and Max Solar Scenarios.

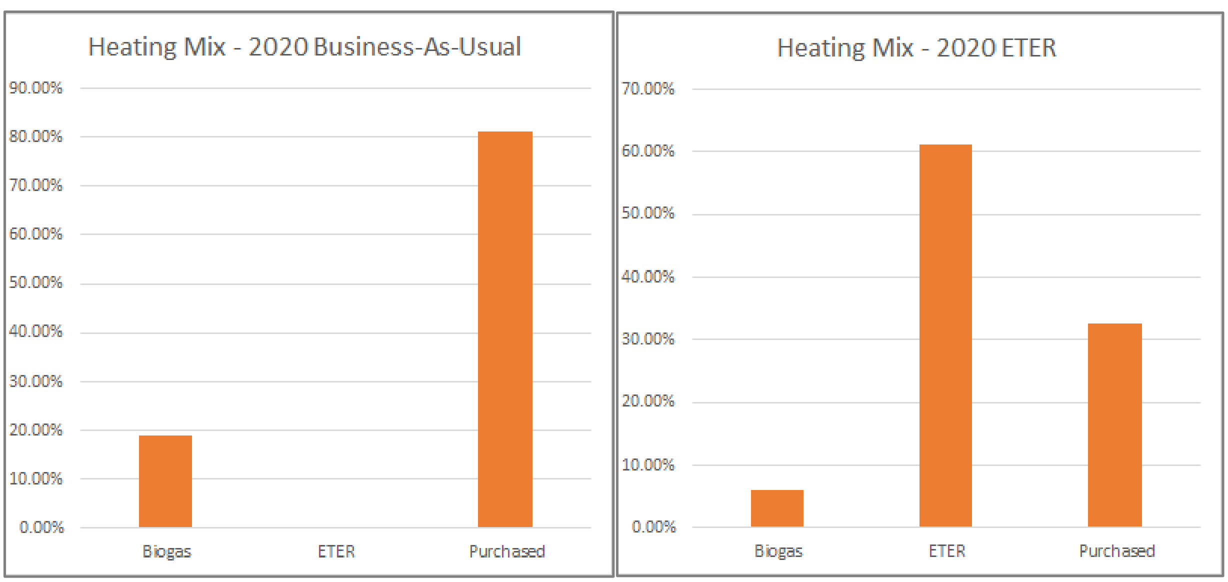

Figure 24. Heating Mix Comparison between Business-As-Usual and ETER Scenarios.

Results and Sensitivity

The LCOE for each scenario is documented in *Table 13*. Given that the capacity of an installed PV array does not significantly offset the energy mix, minimal impact to LCOE is realized when a solar array is installed. As expected, the LCOE only changes from the base case in scenarios that use solar. In addition, note that the LCOE is always lower than the price of purchased electricity from the grid. Biogas causes this observed result, as this existing system has a lower operational cost than that realized from purchasing electricity from the grid.

***Table 13*. Summary of LCOE for Each Scenario.**	
Business-As-Usual	$0.0733/kWh
Max Solar Only	$0.0761/kWh
Sludge Drying Only (No ETER or Solar)	$0.0733/kWh
Sludge Drying with ETER Only	$0.0733/kWh
Sludge Drying with ETER and Solar	$0.0761/kWh

More significant changes occur to the LCOH in each scenario, and this is documented in *Table 14*. This is expected due to the large installed capacity and resulting capital cost of the ETER system. Note that for the LCOH, the calculated values are always greater than the price of natural gas from the grid. This is also due to the biogas, which produces heat at a greater cost than the cost of natural gas from the grid. Although IAWWTF's use of biogas results in increases to the LCOH, it decreases the CO_2 footprint of the plant.

***Table 14*. Summary of LCOH for Each Scenario.**	
Business-As-Usual	$7.83/mmBTU
Max Solar Only	$7.83/mmBTU
Sludge Drying Only (No ETER or Solar)	$7.42/mmBTU
Sludge Drying with ETER Only	$9.87/mmBTU
Sludge Drying with ETER and Solar	$9.87/mmBTU

The NPV metric accounts for all capital costs, operating costs, and savings realized from maximizing the heat used in the sludge drying system, which allows for IAWWTF to avoid the annual $250,000 cost of landfilling sludge output. As shown in *Figure 25*, using natural gas to increase the sludge drying heat (Scenario 3) provides NPV savings of approximately $1.7 million compared to the base case (Scenario 1). When ETER alone is used (Scenario 4), NPV savings are approximately $540,000 relative to the base case. It is important to note that while project

NPVs are negative, they represent expected present values of energy expenditures and any associated cost savings over a 30-year period.

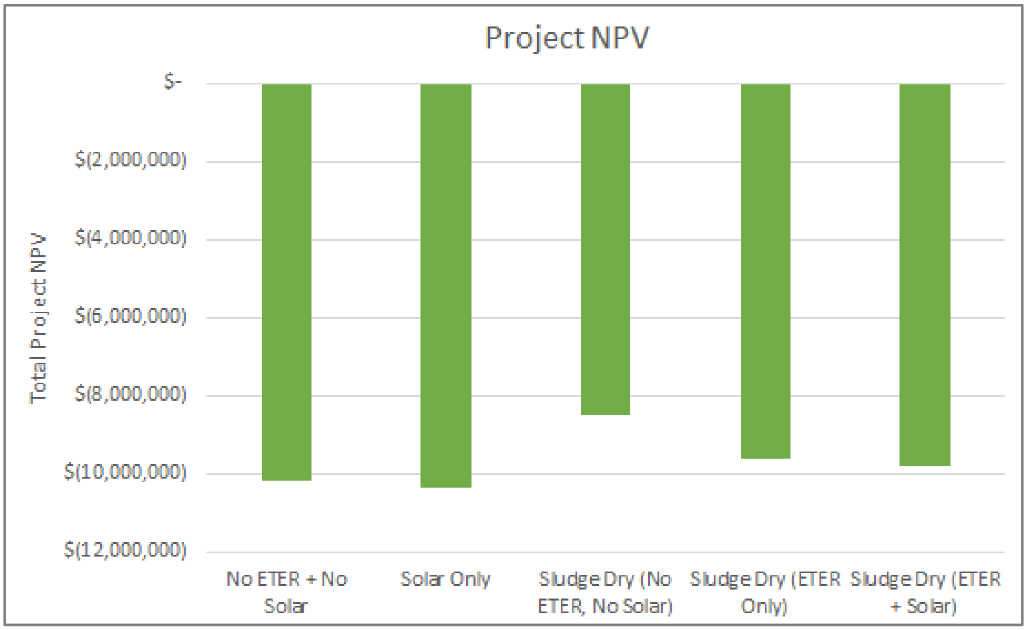

Figure 25. NPV Summary for Each Scenario, Including Sludge Drying Savings.

Utilizing solar alone decreases the project NPV by $187,000, and it appears to be a cost-effective way to reduce carbon emissions from fossil fuels. When the use of renewables on site is maximized (Scenario 5), total NPV savings amount to $353,000. Although savings are realized from ETER, the environmental analysis that follows in this report shows that the total carbon emissions at IAWWTF rise because of the increased heat demand for drying sludge and the electricity requirements to run ETER. Nevertheless, the cost to reduce one ton of CO_2 using ETER and solar can be calculated because ETER provides the energy for the sludge drying system that would otherwise need to be supplied by natural gas. These key values are summarized in *Table 15* and confirms that solar is a more cost-effective method of reducing CO_2 emissions from fossil fuels.

***Table 15*. Cost to Reduce One Ton of CO_2**	
ETER	$90.75
Max Solar Only	$35.11

The economic discussion for this project concludes with a sensitivity analysis, which accounts for variability in parameters for the solar and ETER installations. First, the installed capacity of the solar array is varied from 0 to 400 kW in increments of 100 kW and compared to variability in operation and maintenance costs ranging from $5/kW to $25/kW. These two variables were selected for the sensitivity analysis over capital cost because the capital cost of solar PV arrays has become more predictable over the last few years[38], while operation and maintenance costs vary based on owner preferences for upkeep and the inclusion of items like property taxes and insurance.

As shown in *Figure 26*, it appears that the reasonable range of inputs for the variables results in similar ranges for extreme values of LCOE in the row and column directions. Therefore, it can be concluded that the size of the solar PV array and the determination of operation and maintenance costs are equally important in determining the LCOE.

		Solar O&M Cost ($/kW)				
		5	10	15	20	25
Solar Installed Capacity (kW)	0	$ (0.0733)	$ (0.0733)	$ (0.0733)	$ (0.0733)	$ (0.0733)
	100	$ (0.0737)	$ (0.0738)	$ (0.0740)	$ (0.0741)	$ (0.0742)
	200	$ (0.0742)	$ (0.0744)	$ (0.0747)	$ (0.0749)	$ (0.0751)
	300	$ (0.0746)	$ (0.0750)	$ (0.0754)	$ (0.0757)	$ (0.0761)
	400	$ (0.0751)	$ (0.0756)	$ (0.0761)	$ (0.0765)	$ (0.0770)

Figure 26. Sensitivity Analysis for Solar PV Installation, Operation, and Maintenance.

The sensitivity analysis for ETER compares the impact of capital cost and the impact of maintenance cost estimates. Note that the maintenance cost for ETER is distinct from the operational cost, which is derived from the electricity required to run the system. For capital cost, the variability in data points from the benchmarking cost and market analysis sections suggest that total installation cost may vary from $250/kW to $2,250/kW, depending on factors such as local site conditions and infrastructure requirements. Maintenance costs are estimated to range from $0.001/kWh to $0.005/kWh of energy produced by the system. *Figure 27* shows that the capital cost of ETER may be more critical to determine than the annual maintenance cost. At a capital cost of $250/kW, the LCOH is $7.68/mmBTU, and at $2,250/kW, the LCOH rises to $10.57/mmBTU.

		Annual ETER Maintenance Cost ($/kWh)				
		0.001	0.002	0.0032	0.004	0.005
ETER Capital Cost ($/kW)	250	$ (7.68)	$ (7.85)	$ (8.06)	$ (8.20)	$ (8.38)
	500	$ (8.04)	$ (8.21)	$ (8.42)	$ (8.56)	$ (8.74)
	750	$ (8.40)	$ (8.58)	$ (8.79)	$ (8.93)	$ (9.10)
	1000	$ (8.76)	$ (8.94)	$ (9.15)	$ (9.29)	$ (9.46)
	1250	$ (9.12)	$ (9.30)	$ (9.51)	$ (9.65)	$ (9.83)
	1500	$ (9.49)	$ (9.66)	$ (9.87)	$ (10.01)	$ (10.19)
	1750	$ (9.85)	$ (10.02)	$ (10.23)	$ (10.37)	$ (10.55)
	2000	$ (10.21)	$ (10.39)	$ (10.60)	$ (10.74)	$ (10.91)
	2250	$ (10.57)	$ (10.75)	$ (10.96)	$ (11.10)	$ (11.27)

Figure 27. Sensitivity Analysis for ETER Installation and Maintenance.

[38] NREL (2018).

Environmental Analysis

Solar Installation Details

Considering the many acres of land around IAWWTF and potential rooftop space, it is possible to install solar PV systems on site. The existing land area as shown in *Figure 28* would allow for 400 to 800 kW of capacity for a solar ground installation. A large enough PV array, although beyond the assumed limit of 400 kW used in this report, could provide electricity for all pumps and compressors in the ETER system and also fulfill operational electricity demands at IAWWTF. The use of renewable energy to power the ETER system would further decrease the carbon emissions from fossil fuels that would be generated by the technology.

Figure 28. Potential Area for Ground Solar PV Array at IAWWTF (Outlined in Red).[39]

There are several assumptions made for sizing the solar PV array, including a peak sun hour in Ithaca of 3.79 hours per day, an installation capacity of 400 kW, and a panel size of 250W, measuring 5.5 ft x 3.28 ft. In addition, a 30% efficiency and energy loss factor is applied, leading to a capacity factor of 76.9%. Finally, it is assumed that the panels will be installed at a 42-degree angle to maximize the energy captured at Ithaca's latitude position. Without considering life cycle emissions, solar power is a type of carbon-free energy, meaning that the CO_2 emissions produced by a solar PV array can be considered equivalent to zero.

Using the installed capacity, selected panel size, and the assumed tilt of the array, the number of panels, produced electricity, and the approximate ground installation area can be determined.

[39] Google Maps (2019).

The calculation for the annual electricity output is shown in *Figure 29* that follows. Details summarizing the solar PV array are shown in *Table 16*.

$$Annual\ Solar\ Energy\ =\ Size * Capacity\ Factor * Peak\ Sun\ Hour/Day * 365$$
$$= 400kW * 76.9\% * 3.79\ hr/day * 365$$
$$= 425{,}646\ kWh\ per\ Year$$

Figure 29. Calculations for Solar PV Energy Output.

***Table 16*. Panels and Electricity Output**	
Number of Panels	1,600 panels
Approximate Ground Installation Area	21,450 sf
Estimated Electricity Output	425,646 kWh/yr

Emissions Breakdown at IAWWTF

Based on data provided by IAWWTF and data for similar projects outside of Ithaca, an environmental analysis was conducted. The analysis examined the environmental benefits that the implementation of biogas production, solar production, and the ETER system at IAWWTF could bring.

Prior to starting the analysis, certain assumptions were made. For instance, as detailed in the economic analysis in this report, a scenario maximizing the use of all clean energy sources available for this project results in a 2020 energy profile consisting of 37.65% of electricity demand satisfied through biogas, 11.73% through solar, and 50.62% through purchased electricity. Furthermore, IAWWTF would generate 6.08% of its heating needs through biogas, 61.24% through ETER, and 32.68% through purchased heat. A 1% annual escalation of electricity demand from normal operations is also assumed, and the amount of purchased electricity and heat is calculated for each year in the 30-year project period based on the escalation and the installed capacity of on-site energy sources.

For the environmental analysis at IAWWTF, this report divides the analysis of carbon emissions from fossil fuels into two sections: generation of electricity and generation of heat. As discussed previously, it is assumed that biogas and installed solar arrays do not contribute to CO_2 emissions from fossil fuels. While these technologies could be considered to generate carbon emissions over the course of a life cycle analysis, one key priority at IAWWTF is to reduce the dependence on energy use derived from fossil fuels. The assumption about CO_2 emissions simplifies the environmental analysis and focuses on this priority.

For electricity use, the EPA provides a useful estimate for CO_2 emissions from purchased electricity in New York State, and this is equivalent to 0.41 kilograms of CO_2 per kWh of electricity consumed[40]. Consequently, continuing operations in the business-as-usual case at the plant would result in 36.4 million kilograms of CO_2 emissions due to the consumption of fossil fuels over the next 30-years. Installing a 400-kW solar array is estimated to reduce electricity-based CO_2 emissions from fossil fuels by approximately 5.3 million kg over the project period. The annual production of 425,646 kWh from the solar array is electricity that would otherwise need to be purchased from the grid.

With regards to heat generation, the main source of CO_2 emissions from fossil fuels is the use of natural gas, which is estimated to output 53.07 kilograms of CO_2 per million BTUs consumed[41]. The business-as-usual case for heat consumption at IAWWTF would result in 12.5 million kilograms of CO_2 emitted over the next 30 years. If IAWWTF planned to implement a more thorough sludge drying process, the increased heating demand would raise the CO_2 output to 43.8 million kilograms over the project period, assuming that no additional on-site heating sources are implemented.

The increased heating demand from an improved sludge drying system provides an opportunity for ETER to supply the majority of these needs. While ETER's carbon footprint is the electricity consumed to operate the heat pump and compressor, the technology would save 12.3 million kilograms of CO_2 that would otherwise come from natural gas use in the sludge drying process. However, when comparing the aggregate emissions of the business-as-usual case to the scenario that maximizes the use of all clean energy sources, the business-as-usual case produces less CO_2 over the project period, saving 13.7 million kilograms. It is important to note that an assumed constant CO_2 per kWh for purchased grid electricity over the next 30 years directly contradicts New York's goals of 100% carbon-free electricity by 2030 or 2035. If this is considered, CO_2 emissions from electricity can be further reduced.

Emissions by Scenario and ETER Benefits

The results discussed in the previous section are shown in *Figure 30*, which summarizes emissions for the five scenarios studied in this report. Based on this analysis, it appears that while ETER would provide significant environmental benefits, these benefits are not enough to offset the additional demand of an improved sludge drying system. It is important to note that CO_2 from electricity is affected by the decisions to implement a solar PV array and ETER, while CO_2 generated from heat consumption is influenced by the decisions to use an improved sludge drying system and ETER. When ETER is used, additional electricity is purchased to run the system, increasing the overall emissions at the plant due to electricity. While the mechanisms of heat transfer in the ETER system are carbon-free, the footprint of the technology could be further improved if clean energy is used to power the heat pump.

[40] EPA (2007).

[41] Energy Information Administration (2018).

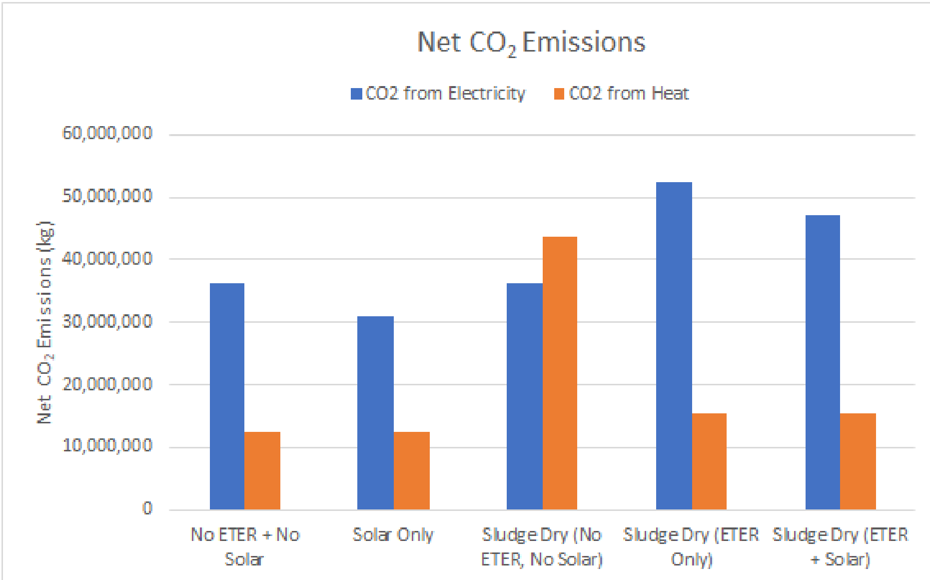

Figure 30. Net CO_2 Emissions by Scenario.

While the size of the ETER system in this report is not large enough to sell excess heat to City Harbor, the potential CO_2 savings from the technology can be estimated. Given that the estimated annual heating demand from City Harbor is 1,080 mmBTU as described in this report's economic analysis, ETER could save 1.7 million kg of CO_2 over 30-years at the development. This assumes that all of City Harbor's space and water heating needs would otherwise be met by using natural gas.

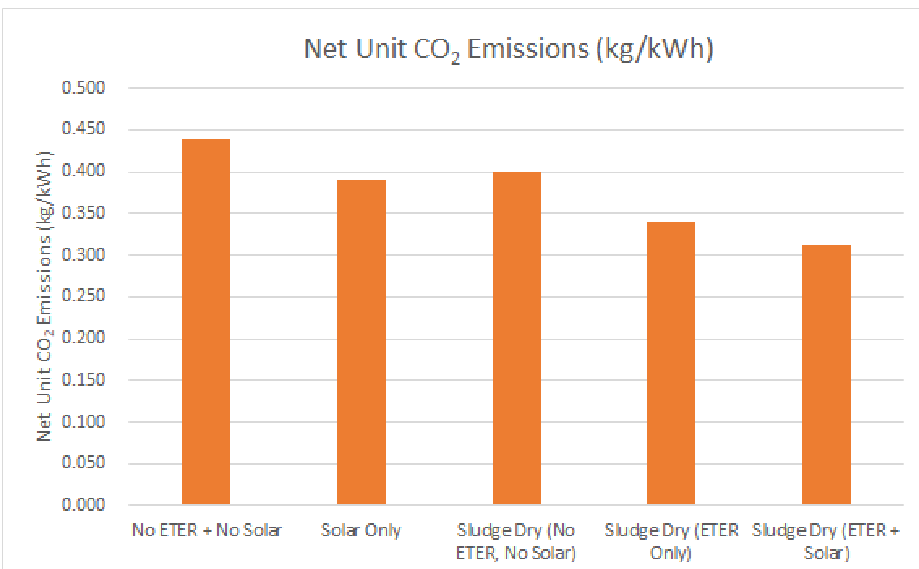

Figure 31. Net Unit CO_2 Emissions per kWh Used.

Figure 31 analyzes the carbon footprint using a different metric, which measures the rate of CO_2 produced over the project lifetime as opposed to the absolute amount emitted. This adjusts emissions for the energy generated under each scenario. The business-as-usual case has the highest net unit CO_2 emissions at 0.438 kg/kWh, which is expected.

While it has been previously demonstrated that the combination of ETER and solar does not decrease the total carbon output at IAWWTF, the rate metric importantly shows that these technologies offer the cleanest energy option out of the ones analyzed in this report. In this scenario, the net unit CO_2 emissions are 0.313 kg/kWh. Future studies may wish to analyze a smaller ETER system that meets the needs of IAWWTF's current operations rather than an improved sludge drying system, as this scenario may lower the aggregate carbon emissions at the plant.

Recommendations

Based on the results of the market, technical, economic, and environmental analyses, an installed heat pump capacity of 660 kW is feasible for IAWWTF. The use of an ETER system at IAWWTF would primarily contribute to additional sludge drying heat, which is a key initiative that the plant is considering in order to realize $250,000 in annual savings.

The analysis in this report shows that while the use of ETER would reduce the carbon footprint of the additional heat, the sludge drying initiative would at best add 13.7 million kg of CO_2 over a 30-year period, or about 458,000 kg of CO_2 per year on average, with both solar and ETER used as energy sources. A key factor relating to the increase in emissions is the corresponding rise in purchased electricity needed to operate the ETER system. However, this is a significant improvement over the scenario in which natural gas is used for the sludge drying heat, which would add 31.4 million kg of CO_2 over the project period, or about 1.05 million kg of CO_2 per year on average. Combining ETER and solar can therefore save an expected amount of approximately 590,000 kg of CO_2 per year relative to the all-natural gas alternative. Increasing the capacity of the heat pump beyond 660 kW to also provide heat for normal operations and sell excess supply to City Harbor will likely reduce the carbon footprint of the plant but eliminate the economic benefits of the system.

It is important to note that this project does not include other potential sources of CO_2 or methane emissions, including those arising from trucking waste and any methane emissions from the landfill. In addition, it is assumed that a constant CO_2/kWh of purchased electricity will persist over the next 30 years, but New York State's goal of 100% carbon-free electricity by 2030 or 2035 suggests that the carbon footprint of purchased electricity will decline. IAWWTF could also choose to pay for carbon-free electricity to power its existing operations or a new ETER system, although this would likely cost more than current alternatives.

Meaningful conclusions can be derived from this report with regards to the economic and environmental viability of ETER relative to solar. *Table 17* on the following page summarizes these results, and it shows that a solar PV array is much cheaper than ETER at reducing CO_2 emissions from fossil fuels given IAWWTF's energy profile. As such, the following recommendations are provided for IAWWTF's consideration.

1. **Prioritize Solar PV Installation**. This is the cheaper way to reduce carbon emissions from fossil fuels at IAWWTF and would reduce CO_2 by 5.3 million kg over a 30-year period, or 176,667 kg of CO_2 per year on average. The capital cost of a 400-kW system is estimated at $732,000.
2. **Explore a Larger Solar PV Installation**. If space permits, a larger solar array could provide a clean electricity source in place of purchased power for operating ETER, further reducing the carbon footprint of the technology.
3. **Focus on Optimizing ETER Capital Costs**. The sensitivity analyses in this report show that the resulting project value and cost of heat for IAWWTF is very dependent on the estimate for total capital cost of implementing ETER.

4. **Explore Options to Sell Dried Sludge**. This report only considered cost savings realized from fully drying the sludge. However, monetizing the dried sludge cake by selling it to other end-users would further improve the economic viability of the ETER technology.

***Table 17*. Summary of Key Findings**	
LCOE: All Clean Energy Sources	$0.0761/kWh
LCOH: All Clean Energy Sources	$9.87/mmBTU
Solar Installed Capacity	400 kW
ETER - Heat Pump System	660 kW
Cost/Ton to Reduce CO_2 - Solar	$35.11
Cost/Ton to Reduce CO_2 - ETER	$90.75
Annualized Savings: Clean Energy Sources	$11,770

Sources

Alp' Vieux Bois. (2019). *Les Bardages Extérieurs Et Intérieurs | Alp'Vieux Bois*. Retrieved from www.alp-vieuxbois.fr/produits,1/sapin-ou-chene,3/les-bardages-exterieurs-et-interieurs,p11.html#.XHmLoPZFyUk.

Arcadis and Malcolm Pirnie. (2013). [Figure a chart of sewer heat recovery installed cost vs. heating capacity]. *Figure 10: sewer heat recovery technology installed cost vs. heating capacity*. Retrieved from https://www.mmsd.com/application/files/8414/8416/2660/Sewer_Heat_Recovery.pdf

Arcadis and Malcolm Pirnie. (2013). *Assessment of sewage heat recovery technology and applicability to the Milwaukee Metropolitan sewerage district*. Retrieved from https://www.mmsd.com/application/files/8414/8416/2660/Sewer_Heat_Recovery.pdf

Baber, C. (2011). *Renewables-based district energy in Vancouver*. Retrieved from https://www.mwrd.org/irj/go/km/docs/documents/MWRD/internet/Departments/MR/Seminar_Series/2011/03-25-2011Renewables-Based_District_Energy_Vancouver.pdf

Baber, C. (2018, November 20). *False Creek Neighbourhood Energy Utility (“NEU”) 2019 customer rates*. Retrieved from https://council.vancouver.ca/20181211/documents/spec1e.pdf

Bloomquist, R. (2003). Commercial and industrial heat pump case studies. *International summer school on direct application of geothermal energy*. Retrieved from https://www.geothermal-energy.org/pdf/IGAstandard/ISS/2003Germany/II/10_1.gor.pdf

Chae, K. and Jihoon, K. Energy Conversion and Management. (2013, November). Estimating the energy independence of a municipal wastewater. *Energy Conversion and Management, 75, 664-672*. Retrieved from https://www.sciencedirect.com/science/article/pii/S0196890413004871

City Harbor. (2019). *Updates - City Harbor*. Retrieved from https://cityharborithaca.com/

City of Montpelier. (2012). *Montpelier district heat customer agreement* [PDF file].

City of Vancouver. (2011). [Figure a screenshot of the False Creek Energy District]. *Vancouver Green Capital*. Retrived from https://vancouver.ca/docs/planning/renewable-energy-neighbourhood-utility-factsheet.pdf

City of Vancouver. (2019). *Southeast False Creek Neighborhood Energy Utility*. Retrieved from https://vancouver.ca/home-property-development/southeast-false-creek-neighbourhood-energy-utility.aspx

Compass Resource Management Ltd. (2012). *Neighbourhood District Energy System for UBC expansion areas*. Retrieved from https://www.corix.com/docs/default-source/regulatory-affairs/ubc-ndes/appendix-2---compass---ubc-final-ndes-business-case-report_nov2012.pdf?sfvrsn=c4b7975c_2

Danfoss. (2019). *Thermal Valves*. Retrieved from www.danfoss.com/en/products/valves/dhs/hydronic-balancing-and-control/thermal-balancing-valves/#tab-overview.

DEC Engineering. (2017, January). *Energy study program*. Retrieved from https://www.whistler.ca/sites/default/files/2017/Feb/related/108/energy_study_program_report_r2.pdf

Energy Information Administration. (2018, February). *U.S. district energy services market characterization*. Retrieved from https://www.districtenergy.org/HigherLogic/System/DownloadDocumentFile.ashx?DocumentFileKey=44c35916-f1af-6bed-2fed-823299b36bde&forceDialog=0

Frazier, L., Gulamaliyev, R., James, G., Kok, I., McKinley, C., Nielsen, L., Paleari, W., Pater, R., Rottau, D., Short, B., and Yu, J. (2015). *Feasibility study for developing a microgrid at the Ithaca Area Wastewater Treatment Facility to serve the Ithaca North Energy District*.

GEA Engineering for a Better World. (2019). *VARITUBE® Tubular Heat Exchangers*. Retrieved from www.gea.com/en/products/varitube.jsp

GEA Refrigeration Technologies. (2012). *Compression Heat Pumps*. Retrieved from https://www.gea.com/en/binaries/Ap_HeatPump_150dpi_A4Size_4C_US_tcm11-12226.pdf

Google Maps. (2019). [Figure a screenshot of IAWWTF satellite view]. *Google Maps satellite view*.

Hart, J. (2011). *Wastewater heat recovery: technologies & applications*. Retrieved from https://www.kwl.ca/sites/default/files/BCWWA2011_JCH2_Presentation.pdf

Insero & Co. (2017). *Ithaca Area Wastewater Treatment Facility financial report* [PDF file].

Kollmann, R., Neugebauer, G., Kretschmer, F., Truger, B., Kindermann, H., Stoeglehner, G., Ertl, T., and Narodoslawsky, M. (2017, July 1). Renewable energy from wastewater - Practical aspects of integrating a wastewater treatment plant into local energy supply concepts. *Journal of Cleaner Production, 155,* 119-129. Retrieved from https://www.sciencedirect.com/science/article/pii/S0959652616313415

Louisiana Division of Administration. (2001). *Guide for capitalization and depreciation of capital assets prepared by the Office of Statewide Reporting and Accounting Policy*. Retrieved from https://www.doa.la.gov/osrap/library/gasb34/01-31%20guide%20for%20capitalization%20and%20depreciation%20of%20capital%E2%80%A6.pdf

Lozano, J. (2018). Ithaca Area Wastewater Treatment Facility Overview. *Ithaca Area Wastewater Treatment Facility*.

Lozano, J. (2019, February). Email.

Lozano, J. (2019, February). Personal interview.

Lytron. (2019). *Custom Heat Exchangers*. Retrieved from www.lytron.com/Heat-Exchangers/Custom.

Malcolm Pirnie, Inc. (2005). *Municipal wastewater treatment plant energy evaluation for Ithaca Area Wastewater Treatment Facility*. Retrieved from https://www.nyserda.ny.gov/-/media/Files/EERP/Commercial/Sector/Municipal-Water-Wastewater-Facilities/mwwt-energy-evaluation-ithaca.pdf

Metropolitan Water Reclamation District of Greater Chicago. (2019). *James C. Kirie Water Reclamation Plant*. Retrieved from https://www.mwrd.org/irj/portal/anonymous?NavigationTarget=navurl://ae5cd65abfbb84b452ab628bd8489bcb

National Renewable Energy Laboratory. (2017). *U.S. solar photovoltaic system cost benchmark: Q1 2017*. Retrieved from https://www.nrel.gov/docs/fy17osti/68925.pdf

National Renewable Energy Laboratory. (2018). *Costs continue to decline for residential and commercial photovoltaics in 2018*. Retrieved from https://www.nrel.gov/news/program/2018/costs-continue-to-decline-for-residential-and-commercial-photovoltaics-in-2018.html

National Renewable Energy Laboratory. (2019). *PVWatts calculator*. Retrieved from https://pvwatts.nrel.gov/pvwatts.php

New York State Energy Research and Development Authority. (2019). *Current funding opportunities, PONs, RFPs, and RFQs*. Retrieved from https://www.nyserda.ny.gov/Funding-Opportunities/Current-Funding-Opportunities

O'Connor, K, and Crandall, B. (2018, January 24). A look at updated plans for City Harbor. *Ithaca Voice*.

Pacific Institute for Climate Solutions. (2012, May). *The regulation of district energy systems*. Retrieved from https://pics.uvic.ca/sites/default/files/uploads/publications/WP_District_Energy_May2012.pdf

Pound Sterling Live. (2019). *U.S. Dollar to Canadian Dollar spot exchange rates for 2010 from the Bank of England*. Retrieved from https://www.poundsterlinglive.com/bank-of-england-spot/historical-spot-exchange-rates/usd/USD-to-CAD-2010

Ramsted, K. (2018, May 2). Metro Vancouver's vibrant district energy market. *International District Energy Association*.

Resort Municipality of Whistler. (2019). *District Energy System*. Retrieved from https://www.whistler.ca/services/water-and-wastewater/district-energy-system

Resort Municipality of Whistler. (2010). *Whistler Athletes' Village*. Retrieved from https://www.whistler.ca/sites/default/files/2017/Oct/related/108/des20presentation.pdf

Sauder School of Business. (2011, October). *Integrated community energy system business case study*. Retrieved from https://www.sauder.ubc.ca/Faculty/Research_Centres/ISIS/Research/Low_Carbon_Economy/~/media/Files/ISIS/Reports/Carbon%20Management%20Reports/QUEST-ICES-Business-Case-Southeast-False-Creek-Neighbourhood-Energy-Utility.ashx

State of New York Comptroller. (2016). *Ithaca Area Wastewater Treatment Facility energy cost savings*. Retrieved from https://www.osc.state.ny.us/localgov/audits/jointacts/2016/ithacawastewater.pdf

Thermax Global. (2018). *Heat Pump, Closed Loop Cooling Tower*. Retrived from www.thermaxglobal.com/thermax-absorption-cooling-systems/heat-pump/.

Thermax Global. (2018). *Valves, Closed Loop Cooling Tower*. Retrieved from www.thermaxglobal.com/steam-accessories/valves/.

Thomas Net. (2019). *Types of Heat Exchangers*. Retrieved from www.thomasnet.com/articles/process-equipment/heat-exchanger-types.

Tredinnick, S. (2013, June 7). Why is district energy not more prevalent in the U.S.? *HPAC Engineering*.

Triami Media BV. (2019). *Historic inflation Canada - CPI inflation*. Retrieved from https://www.inflation.eu/inflation-rates/canada/historic-inflation/cpi-inflation-canada.aspx

United States Department of Energy. (2014). *Industrial heat pumps for steam and fuel savings*. Retrived from www.energy.gov/sites/prod/files/2014/05/f15/heatpump.pdf

United States Energy Information Administration. (2018). *How much carbon dioxide is produced when different fuels are burned?* Retrieved from https://www.eia.gov/tools/faqs/faq.php?id=73&t=11

United States Environmental Protection Agency. (2007). *State electricity and emissions rates*. Retrieved from https://www.miloslick.com/EnergyLogger_files/State_Electricity_and_Emissions_Rates.pdf

Village of Bellevue, Wisconsin. “Green Bay Metro Sewerage District Tours - No Golden Ticket Required.” *Village of Bellevue*, Village of Bellevue, Wisconsin, 0AD, villageofbellevue.blogspot.com/2012/07/no-golden-ticket-required.html.

Whistler Infrastructure Services. (2016, October). *2016 District Energy System annual report*. Retrieved from https://www.whistler.ca/sites/default/files/related/2016_des_annual_report_1_1.pdf

Whistler Infrastructure Services. (2017, October). *Cheakamus Crossing DES recommendations*. Retrieved from https://www.whistler.ca/sites/default/files/2017/Oct/related/108/2017-10-03_des-report.pdf

Wikipedia. (2019). *Heat Pump*. Retrieved from en.wikipedia.org/wiki/Heat_pump

Yaxiu, G., Huqiu, D., Yu, G., and Huanjuan, Z. (2011, May). The potential of urban wastewater heat: The feasibility analysis of using wastewater source heat pump. *2011 International Symposium on Water Resource and Environmental Protection*. Retrieved from https://ieeexplore.ieee.org/abstract/document/5893305