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IQP Report:

Feasibility of a Microturbine on Worcester Polytechnic's Campus

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2 Table of Contents

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4 Abstract

As Worcester Polytechnic Institute aims towards an energy efficient campus, the use of cogeneration technologies can reduce carbon emissions and utility provided electricity by using turbine exhaust for thermal usages and to generate clean, onsite electrical power, respectively. Through means of case studies, personal interviews, and billing assessments, the feasibility of a microturbine, a cogeneration technology, on the campus is determined. A microturbine when implemented correctly, is a feasible energy source to increase Worcester Polytechnic Institute's sustainability on campus.

5 Introduction

Alternative energy systems are the forefront of technology today. People are constantly developing new technologies that help save the environment from waste and pollutants. New technologies use renewable, reusable, and sustainable materials from the earth to produce power, including but not limited to the capture of methane gas to run a generator, biofuels, wind, solar, and tidal. These materials provide the essential, hypothetical green power, but there are no systems that are capable of capturing and converting renewable fuel sources into one hundred percent ecofriendly energy. This is why certain technologies are developed to reduce carbon footprints and to act as an intermediate between now and when the perfect sustainable technology is found. These median technologies allow upwards of eighty percent and ninety percent efficiency. These technologies fall under the realm of cogeneration technologies. The technologies use alternative fuel sources but maximize efficiency of the system by using the exhaust gas to produce hot water for the a system or cold water if run through a heat absorber. The most common technology of the median technologies is the microturbine. Microturbines are a cogeneration system with high efficiency percentages. Microturbines are an ideal energy solution for large-scale buildings or joined neighborhoods. The question we ask is if it is feasible to implement a microturbine on Worcester Polytechnic Institute's (WPI) campus.

Worcester Polytechnic Institute is a strong candidate for a microturbine because of the constant power needed to keep the campus powered on and running. Although a strong candidate, not all buildings and locations are fit for a microturbine. Even though each building could introduce a microturbine to its system, choosing a building with constant high demands of electricity and thermal loads should be done to optimize the efficiency of the microturbine. Worcester Polytechnic Institute is headed towards an energy efficient campus and aims to be as green as possible. "WPI will work to advance the three pillars of sustainability – environmental preservation, economic prosperity, and social equity ("Campus Sustainability Plan" 1)." Worcester Polytechnic Institute's campus has solar panels to offset the cost of heating the pool in the Sports and Recreation Center. Multiple small designed wind turbines around the campus rooftops, and a green roof on East Hall are a few of Worcester Polytechnic Institute's green images. ("Energy & Water Conservation" 1) WPI, an institution based on engineering technologies and scientific motives, is the perfect cite for a microturbine. With constant upgrades and developments to WPI's campus, the implementation of a microturbine in a retrofit project or new building project is perfect.

The implementation of a microturbine is ideal on paper. It is energy efficient in the mechanics secondary systems and tertiary systems that stem off from it. But will a microturbine and WPI's campus mesh with the building being studied? Campus buildings are full of activity. The buildings are home to science laboratories, computer laboratories, dining halls, and dormitories. All of these rooms need consistent and specific room temperatures. The ratio between the building needs and microturbine capacity need to be determined. Building needs can be found by consulting facility managers to acquire the information on the electrical needs of the building, how many kilowatts a building uses per hour, how much hot water the building uses, and what is the thermal load of the building? These numbers can be assessed and from them a specific size microturbine can be used to place a desired load capacity of the microturbine to offset the building needs, thereby reducing the need for an external supply of heat and power.

No existing technology has been developed to be one hundred percent renewable, sustainable, or reusable and one hundred percent efficient. Because of this, the microturbine is a great alternative and great mediator between being wasteful with the dwindling fuel sources the planet provides us and being one hundred percent reliant on alternative energies and fuels. The system is able to operate on its own producing cost efficient base thermal loads and is able to reduce the electrical base load on the main power grid. It is a great technology to produce electricity for thousands of people and buildings. The microturbine works in parallel with the main power grid but acts as a stand-alone system when producing hot water and cold water. Without the microturbine and the quick implementation of the technology, the world will keep wasting oil and inefficient gas because the in home systems and buildings are not up-to-date. Microturbines are essential for the near future. The goal is to demonstrate the necessity of the cogeneration technology.

The term alternative energy involves a variety of power generation sources. Usually, it refers to electrical power created from renewable resources such as solar or wind energy. This is opposed to single-use resources such as oil or coal. The most commonly used forms of alternative energy today are wind power, solar power, and hydropower. ("Renewable Energy Sources in the United States"1) The benefits of using renewable or alternative energy sources are substantial. From an environmental viewpoint, solar, wind and hydropower are all non-emission power sources. Unlike a power plant, which pollutes the environment substantially, these ecofriendly alternative energy supplies give off low emissions and are safer for the environment. ("Renewable Energy Sources in the United States" 3) On top of the low emissions and little waste products, no valuable non-renewable resources are being used with renewable resource power generation. No matter how much of the planet is using water, wind, or solar, we will never run out. These sources of energy are free and abundant. This thought draws many people to the alternative energies. For any home or building currently relying on the grid's electrical power, an alternative energy system has even more benefits. Power generated from alternative resources can be stored in a battery to provide backup power if utility power from the grid fails. In some areas alternative energy that is generated can be sold back to the local utility company, resulting in lower monthly electric bills at the very least. ("DSIRE: Incentives/Policies by State: Incentives/Policies for Energy Efficiency" 1)

With all these potential benefits, one may wonder why alternative energy systems are still relatively uncommon. Unfortunately, despite continuing advances in the trade, in many cases there are still significant financial downsides to relying on alternative energy as a stand-alone power source. For major companies, businesses, or any given establishment, there are a couple of major constraints that keep them from using large-scale alternative energy generation. The cost of implementing a wind energy system or solar energy system can be extremely expensive when compared to the cost of upgrading or maintaining their current source of energy. In addition, installing an adequate number of large solar panel groupings or large wind turbines to produce the huge amounts of energy required by a given building or establishment takes up a great deal of space that may not be available. ("Catalog of CHP Technologies" 1)

Wind energy is a renewable energy that is very beneficial when it can be properly utilized. Wind energy is harnessed using turbines that generate electricity when the wind turns them. Wind turbines are usually quite large and are located either on land or offshore. Because of the size, wind turbines need a large amount of area to be built on and can't be placed easily in densely populated areas like cities. Wind turbines also need proper wind flow to maximize their output, and the location may have varying wind speeds. "Wind turbines start operating at wind speeds of 4 to 5 meters per second and reach maximum power output at around 15 meters/second" ("Hurwitz: The Fallacy at the Core of Wind Power" 1). Turbines generally have a long life span, between twenty and thirty years depending on location. Wind turbines are however, quite loud depending on how far from them you are, which can be problematic at times. Because of this, many people turn towards a quieter, alternative energy. ("Catalog of CHP Technologies" 3)

Solar energy is a renewable energy that can be made use of relatively anywhere and provides some of the cheapest home water heating available. By placing solar panels on top of roofs or around buildings, the Sun's rays are converted into clean renewable energy. Because different areas on the planet receive varied amounts of sunlight, solar panels are not as useful as they are in some places. ("The Power of Renewables" 4) Places of warmer temperature can usually make more use of solar panels than places that are colder year round. Solar panels also do not give a very high amount of energy per panel, so often a larger surface area must be covered with panels to generate higher amounts of energy. While solar panels make use of the Sun and its renewable energy, they do suffer from the fact that the Sun is not always present. A big issue solar panels face is storing the energy they produce for periods of time where there is less or no sunlight. Solar panels also become less efficient in dusty areas. The dust accumulates on the panel and disrupts the sunlight that hits the receptors in the panel. ("The Power of Renewables" 1) Without proper maintenance and cleaning, solar panels become very ineffective and efficiency lowers drastically.

Comparing microturbines to wind and solar energy should be assessed open-mindedly. While wind and solar energy are renewable and require no fuel source like microturbines, they do have other requirements that limit how and where they can be used. Firstly, the size of the necessary holding space that would implement one of these energy sources would be factored in when selecting one. Wind turbines are very large and a desired location might not have the square footage to have one implemented that is properly sized. A small wind turbine does not produce the same amount of energy that a microturbine can produce. ("European Wind Energy Association" 2) Also, in order for solar panels to produce the same amount of energy as a microturbine, a small solar field would need to be built.

Maintenance is another issue that must be taken into consideration. Both solar panels and wind turbines must be placed outside for them to function. By being outside, the machines are subject to the wear and tear by the outer elements. Microturbines can be placed inside since their exhaust is captured and used for various systems. Microturbines also run off of a single moving part, which in turn reduces the maintenance. (Capstone – Wikipedia 1) Finally, any given location may also not have suitable conditions for solar or wind power. If the location receives low amounts of sunlight or does not have consistent levels of wind, it would not be able to make full use of solar or wind energy options, respectively. Microturbines on the other hand, can be used in any environment and their effectiveness and operation is not indicative of the environment they are placed in. However, microturbines are not renewable energy resources like solar and wind energy, they do require fuel to operate. However, with the wide variety of fuel they potentially could run on, microturbines act as a halfway point between traditional sources of energy and less reliable renewable sources.

Although there are many positive outlooks on renewable energies and cogeneration systems, it is indicative to look at the negative points of each. One of the biggest concerns of the forerunners of alternative energies and renewable energies is the impact on the environment. All energy sources have an impact on the environment, whether it is during the manufacturing process of the product or the emissions of the fuel while it is running.

Most fossil fuels such as natural gas, oil and coal inflict substantially more harm than sustainable energy sources, including damage to public health, wildlife and habitat loss, air and water pollution, global warming emissions, and water use. ("US Environmental Protection Agency" 1) However, it is still important to understand the environmental impacts associated with producing power from renewable sources such as solar energy, wind energy, and cogeneration energy. The type impact that the technology has on the environment varies depending on the specific technology being used, the geographic location, and other numerous factors. By understanding the current and potential environmental issues associated with each renewable energy source, we can takes steps to effectively minimize or even avoid these impacts as they become a larger portion of our electric supply. ("Catalog of CHP Technologies" 1)

Generating power from the wind is one of the most sustainable and cleanest ways to generate electricity, as it produces no toxic pollution or global warming emissions. Wind is also abundant, inexhaustible, and affordable, which makes it a viable and large-scale alternative to fossil fuels. Despite its potential, there are a variety of environmental impacts associated with wind power generation that should be recognized. One of the major concerns with regards to wind turbines and wind farms is their impacts on the inhabitants, both human and animal, that live in close proximity to these sites. Birds are most likely to be adversely affected by wind farms. These species are susceptible to things such as disturbance, habitat loss and collisions. According to the Royal Society for the Protection of Birds, "if wind farms are located away from major migration routes and important feeding, breeding, and roosting areas of at-risk bird species, it is likely that they will have minimal impacts ("Environmental Impact of Wind Energy" 1)." Another concern is the effects that wind farms and wind turbines have on people living in proximity to the sites. Residents living near wind farms also have both psychological and physiological complaints. Some complain of not being able to sleep due to turbine noise, and psychological issues due to the low decibel sound and vibration that the turbines produce. An IQP done by previous students had to factor in all of these environmental impacts when it came to their project. They came up with a plan to implement a wind turbine at Holy Name High School in Worcester, MA. The end result was a standing turbine erect in downtown Worcester. Not only did they design a plan for the turbine, they looked into the feasibility of the wind turbine and if, in the long run, it would be worth it. **("**Holy Name High School Wind Feasibility Study" 1)

Like wind power, the sun provides a tremendous resource for generating clean and sustainable electricity. The environmental impacts associated with solar power can include land use and habitat loss, water use, and the use of hazardous materials in manufacturing, though the types of impacts vary greatly depending on the scale of the system and the technology used. ("The Power of Renewables" 1)

Cogeneration power plants generally include reciprocating engines, combustion turbines, micro-turbines, and backpressure steam turbines. Cogeneration power plants often operate at fifty to seventy percent higher efficiency rates than single-generation facilities. In practical terms, what cogeneration usually entails is the use of what would otherwise be wasted heat (such as a manufacturing plant's exhaust) to produce additional energy benefits, such as to provide heat or electricity for the building in which it is operating. Cogeneration is great for the bottom line and also for the environment, as recycling the waste heat saves other pollutant spewing fossil fuels from being burned. While cogeneration provides several environmental benefits by making use of waste heat and waste products, air pollution is a concern any time fossil fuels are burned. The major regulated pollutants include particulates, sulfur dioxide, and nitrous oxides. ("US Environmental Protection Agency" 1)

Microturbines are a great halfway point between the outdated fuel guzzling technology and the future one hundred percent efficient sustainable technologies. They are a developed technology to provide reductions on the load and dependence of the power grid for all energy needs. A microturbine would be perfect for Worcester Polytechnic Institute's campus if and only if certain requirements can be met. The microturbine must run at maximum capacity to evoke the highest efficiency the microturbine can provide. The microturbine will fit into the ethics of sustainability WPI has and will create a sense of accomplishment for the sustainability advocates. The daily usage of all functions must be assessed in order to properly size a microturbine. During the assessment it should be noted that a microturbine running at one hundred percent is more efficient than a microturbine running at eighty percent. The microturbine would be idea for an environment that needs constant temperature such as a computer lab, a room that needs hot water for sterilization, or a large classroom.

6 METHODS

Many people need to see to believe. Actively talking to users of a microturbines will help to assess and analyze the feasibility for others to implement a microturbine system on their own property. Through the methods below, we will be able to properly determine if a microturbine is feasible on Worcester Polytechnic Institutes campus.

Diving into case studies will show results and savings that people like to see. Low costs and big savings is a comfort in the minds of some. From case studies we can see what a certain company uses for a microturbine size to accommodate their needs. We have general questions that need to be answered based on case studies that will lead to more specific questions. The case study that we are primarily looking into is East Hartford High School. We also would like to obtain information regarding the microturbine operations at Syracuse University and Salem Community College. All of these case studies are located in the northeast, vary in energy usage, microturbine size, and are all educational facilities. Forming case studies are very important because they help in a proper assessment of the needs of certain companies.

The use of interviews can prove to be very useful if done correctly. Interviews are useful in the fact that having a conversation face to face with someone will allow professional contact. Information will be gathered on the efficiency of the microturbine for the case study companies, the uses the microturbine has for the companies, and the payback period of the microturbine.

Our goal for Worcester Polytechnic Institute's (WPI) campus is to find a building where one can implement a microturbine that will satisfy the needs of the building with the highest efficiency rating. In order to properly size a microturbine it is necessary to determine the annual energy demand and usage patterns. Also, a factor in determining the size of the microturbine is the energy requirement of a building. It is necessary to determine if the building will utilize the cogeneration availability of the system. This means the building will use the exhaust of the microturbine, along with a heat exchanger or absorption chiller, to make hot or cold water respectively. Creating hot and cold water will increase the load on the microturbine and will allow for optimum efficiency. It is necessary to talk to energy professionals such as NSTAR employees and facility engineers on Worcester Polytechnic Institute's campus to gain information needed to properly fit a microturbine. By consulting these people we will be able to conclude cost, efficiency, and feasibility of a microturbine on WPI's campus.

First, we must determine where to implement a microturbine. Every building has different needs and the location of the microturbine is essential. This is an important step of the installation process to consider. If the microturbine is small enough could it be installed on the roof or must it to be on land? This can also be found out from the manufacturer or installer. Microturbines are extremely quiet but there may be distance requirements for the allowed distance between residential buildings and public buildings. If this is an issue can the microturbine be housed in a certain sound proof housing? This will also be determined when the location is determined.

7 SUSTAINABILITY GOALS

7.1 MASSACHUSETTS AND WORCESTER GOALS ON RENEWABLE ENERGY

In Massachusetts, the Patrick Administration determined a target of achieving greater than twenty-five percent of Massachusetts' energy from alternative sources or renewable energy by 2020. This is including solar, wind, hydro, turbine, and biomass. A statement by the Office of Energy and Environmental Affairs makes it clear that that does not necessarily mean taking older power plants offline:

> Under Governor Patrick's leadership, Massachusetts has established the most aggressive greenhouse gas reduction goals in the nation, earned the number one ranking in energy efficiency two years in a row, and is an active participant in the Regional Greenhouse Gas Initiative. We also continue to pursue renewable energy sources aggressively in order to diversify our portfolio and provide clean, homegrown energy sources in Massachusetts. Meanwhile, energy reliability remains critical to the economy and our citizens' well-being. While we anticipate that coal will become a declining percentage of the Massachusetts resource mix, and the percentage of clean renewables will increase, we are working to ensure that we achieve our goals without jeopardizing reliable energy supply. (EEA Home 1)

There has been a heavy decline in coal and oil use in New England in recent years. In 2010, coal and oil fueled more than forty percent of New England's energy production. That number today is less than 5 percent, according to ISO New England's 2013 Regional Electricity Outlook. Adding on that point, the number of new coal plants being built has fallen off in recent years. Natural gas has taken up the slack, now accounting for more than forty eight percent of Massachusetts's power supply. ISO New England says that's resulted in lower energy costs and reduced emission rates for greenhouse gases, including nitrogen oxides, sulfur dioxide, and carbon dioxide. But there's also a downside. The pipelines that bring natural gas to New England can be unreliable. ISO New England cites over reliance on natural gas and aging oil/coal infrastructure as the number one challenge facing New England's energy system. ("Massachusetts' Quest for Renewable Energy" 1)

Progress toward the Patrick administration's renewable energy initiatives and goals has not been what was expected. Energy sustained from wind development has been much slower than hoped, but solar power has grown tremendously. In May, Massachusetts state officials announced that the original solar goal set in 2007 of 250 megawatts of commercial and residential solar energy had already been reached an impressive four years in advance, thus setting a substantial new goal of 1,600 megawatts by 2020.

Environment America recently put out a report that ranked Massachusetts 7th in cumulative installed solar capacity among states, and cited the Commonwealth as an example of "setting ambitious but achievable goals and backing them up with policies that work." (Environment Massachusetts 1)

In Worcester, the City now offers the Worcester Energy Program. This is a public energy efficiency program that aims to help businesses, institutions, and residents throughout Worcester to take action to save energy. Worcester Energy continues Worcester's long-standing commitment to being green. Currently, the Worcester Energy Program offers a Residential Rebate Pilot, a city-wide effort aimed at increasing energy savings for residences. The City of Worcester established itself as a leader in adopting energy policies that earned it the State's prestigious Green Community designation. Worcester was one of the first thirty-five cities to achieve that status. ("Worcester a Greener Future, Today" 1)

The City of Worcester has recently been designated a "Green Community" by the Commonwealth under the State's Green Community Act. The Green Community designation is of the highest recognition the City can receive for energy efficiency efforts and well positions the City to successfully capture significant grant funds from State and Federal sources, which will be used to maintain existing projects, along with establish new renewable energy projects. The City, through the Energy Efficiency and Conservation Program, actively pursued the State's designation as a Green Community as part of its Climate Action Plan goals. In order to achieve this Green Community designation, the City was required to satisfy the five requirements; Siting for Renewable/Alternative Energy Projects; High Fuel Efficiency Vehicle Fleet Purchase Policy; Twenty percent Municipal Energy Use Reduction Plan; Expedited Permitting for Eligible Energy Facilities; and Adoption of Energy Efficient Building Code.

The Green Communities Grant Program and Designation has helped over 123 of Massachusetts's towns and cities earn the Green Community designation. As energy leaders in the State, Green

Communities are eligible for Massachusetts State grants, due to being the energy leaders in the state. Over 28 million dollars, from grants, is already at work in 110 communities, with over 2 million dollars in additional grants for energy projects in the 13 newest designated communities. The Green Communities Division continues to work with other local government organizations on a variety of energy activities. Those include reducing energy use in school and municipal buildings to establishing purchase agreements that produce renewable energy generation that is financially rewarding. ("Green Communities Designation and Grant Program" 1)

8 HISTORY OF MICROTURBINES

"Gas turbines, or combustion turbines are a type of internal combustion engine with an upstream rotating compressor combined with a downstream turbine, and combustion chamber in the middle." The history of the gas turbine is where the microturbine took its structure. ("Gas Turbine" 1)

The first instance in recorded history of a turbine like design was drawn by Leonardo da Vinci around the year 1500, called the "Chimney Jack". The drawing showed hot air rising from a fire through a single-stage axial turbine rotor mounted in the exhaust duct in the fireplace and turning the roasting split through a gear-chain reaction. Next in 1678, Ferdinand Verbiest build a model carriage, which relied on a steam jet for power. In 1791 John Barber was recognized for the first true gas turbine and received a patent for his invention, which showed a lot of similarities and had a lot of the same components as modern day gas turbines. In 1894 Charles Parsons patented the idea of powering a ship with a steam turbine. He built a demonstration vessel, which was the fastest vessel afloat at the time. ("Gas Turbine" 1)

In the early 1900's, advancements with this technology began to become more frequent. A Norwegian named Egidius Elling built the first turbine that could generate enough power to run its own components and produced 11 horsepower. In 1937, the jet propulsion engine, designed by Frank Whittle, ran for the first time and received government funding for its further development. From Whittle's company emerged better engineering resulting with the modern day gas turbine system fundamentals.

The front-runner in the microturbine technology is Capstone Corporation which was the first company to market with commercially practical air bearing turbine technology. The theory behind the microturbine is that it is a technology that can use natural gas, or whatever chosen fuel source, to supply electricity as well as heating and cooling to a building or facility. This type of alternative energy may be a larger initial cost but is supposed to have extremely short payback periods when compared with other alternative energies such as wind or solar power. ("Capstone Turbine Corporation" 1)

9 MICROTURBINE TECHNOLOGIES

9.1 BACKGROUND OF THE KILOWATT

The kilowatt is equivalent to one thousand watts. A single watt is the "rate at which work is done when one ampere of current flows through an electrical potential difference of one volt ("Watt" 1)."

$$W = V * A$$

An electrical consumer monitors electric usage by the amount of kilowatts used over an hour span. A kilowatt-hour is equivalent to one thousand watts expended over the time period of one hour. "If the energy is being transmitted or used at a constant rate over a period of time, the total energy in kilowatt-hours is the product of the power in kilowatts and the time in hours ("Kilowatt" 1)." A company or homeowner is billed based upon the electrical usage of the building. There is a set price that one pays for electricity. Usually there is a utility charge and a third party company cost. The utility charges a small fee for the transportation of the electricity, while the third party charges the greater of the two for the production of the electricity.

A microturbine is able to generate its own electricity because of the single shaft mechanism that rotates the generator. The generators within the turbine cycles are able to generate large amounts of wattage. This energy produced is used throughout buildings to power lights, different machines or mechanisms, and pumps to keep buildings as efficient as possible. With the turbine creating its own electricity there is limited need for third party and utility power. Creating onsite power will lower the electrical cost for maintaining a building.

9.2 COMPONENTS AND INNER WORKINGS

The complete microturbine system is comprised of eight components. These components include the inverter, the rectifier, the generator, the compressor, the turbine mechanism, the combustor, the recuperator, and the exhaust heat recovery unit. Each mechanism of the looped system has its own functionality but together create an energy efficient and durable machine.

A cold start begins with the dual action of the combustion chamber, or combustor, receiving a precise mix of air and fuel. The combustor is one of the highest factors in maintaining 'green levels' of emissions and fuel efficiency due to the gasses released during the reaction within the system (McMahon, Mary, and O. Wallace 1). To sustain these levels and efficiencies, the combustor must maintain a high air temperature while also sustaining a constant flow rate through the combustion chamber. The combustor will ignite the given fuel to increase the temperature of the air and pressure of the chamber. The chamber is simultaneously fed more air to maintain the combustion rate to increase efficiency. The increase in pressure directly translates to work on the shaft that connects the generator, compressor, and the turbine (McMahon, Mary, and O. Wallace 1).

The high temperature air is then fed from the combustor to the turbine blades. This forced air spins the turbine blades, which in turn spins the shaft that is connected to the compressor and the generator. The compressor has an intake valve that takes in air and compresses the air. (Design 2) This increases the temperature and pressure of the air. This compressed and heated air is then sent to the recuperator to be mixed with exhaust heat from the turbine. The waste heat from recuperator is sent either back to the combustor to reduce fuel needed to maintain certain temperatures or to a heat recovery system where the clean air will be sent to directly heat spaces or water for any type of building; office, homes, hospitals, etc. The heat recovery system is where a microturbine boosts efficiency from about twenty-five to eighty-five percent. ("Design and Function of a Turbocharger: Compressor" 1)

The single shaft is also attached to the generator of the system. The generator beings the cycle by turning the single-shaft until the compressor has the ability to take over and help run the system without the help of the generator. The generator is connected electrically to the rectifier and the inverter. The rectifier is an electrical device that converts alternating current to direct current that can be used in homes to power everyday devices ("Rectifier" 1). The connected inverter will then revert the direct current to alternating current. This dual stage converter process and inverter process cleans the electricity making the electricity cleaner and in turn more efficient. ("Rectifier" 1) The rectifier can be used as a power converter to inject power generated from the microturbine to the grid and a shunt active power filter to filter and "compensate current unbalance, load current harmonics, load reactive power demand and load neutral current." ("Singh" 1)

9.3 COMBINED HEAT AND POWER

Combined heat and power allows a microturbine to be energy efficient. Combined heat and power, or CHP, is known as cogeneration because of the generation of thermal energy and electricity in a single operation. The exhaust heat from the turbine engine is reused immediately after discharge and is pushed through an absorption chiller or heat exchanger. The heat exchanger or absorption chiller will use the hot exhaust to produce warm water or cool water to be used through a heating cycle or cooling cycle.

Cogeneration is an up and coming technology with many different uses but with one common goal. Community homes to multi-million dollar companies are implementing this technology at their apartment complexes and manufacturing plants to reduce carbon footprint and to remain as energy efficient as possible. Many institutions such as East Hartford High School, Syracuse University, and Massachusetts Maritime Academy all have microturbines on their campuses. ("Solution – CHP 1)

There are many benefits to using the cogeneration technology. This technology will reduce costs and save as much as forty percent on electricity from the grid combined with the heat generated by the boilers at the location of the machine. (Combined Heat and Power, 1) Another key aspect is how efficient these machines are. In addition to offereing cost reduction and cost efficientcies, microturbines are energy and resource efficient. The microturbine uses an efficient amount of fuel to produce the electricity and the heat to power and heat homes and buildings. ("Combined Heat and Power (CHP)" 2)

These are not the only benefits to combined heating and power. Cogeneration can be used as standalone power and the building does not need to be on the grid to remain running. Cogeneration is great for onsite and extended power outages. This is an important idea when designing new laboratories or retrofitting old laboratories. If the laboratories were to lose power, all important work and data would not be lost. The microturbine, already a substitute for power from the grid, would continue to run and produce electricity and keep rooms and laboratories at specified temperatures. ("Solution – CHP" 1)

9.4 WASTE HEAT RECOVERY

The heat recovery system is where the microturbine gains efficiency. Imagine a car engine. As the car engine works it produces extremely hot exhaust. This gas is hot enough to burn your skin. This exhaust is released into the atmosphere unused. With a microturbine this hot exhaust is captured and is directed through the system to a heat absorber. The heat absorber is lined with tubing with cold water running through the pipes. The hot exhaust from the turbine flows over the cold water pipes warming the water. This warm water is then sent through the building to be used. The recovery of the exhaust allows for the minimum expense to heat water and sometimes is nearly cost free. The spent exhaust gas is then filtered before released into the atmosphere. ("Waste Heat Recovery" 1)

However, this is not the only application of the heat recovery system. The waste heat recovery system can be the first in line to produce the energy. Like above, waste heat from an exhaust source travels through to a chamber that is home to a series of pipes with water being constantly circulated. The circulated water becomes steam. This steam is then used to power a steam turbine that will generate electricity to operate a building. (U.S. Department of Energy 1)

10 CASE STUDIES: IMPORTANCE INTRODUCTION

When we began our research on Capstone's micro-turbines, we looked into case studies of installations of the many types of turbines. Of those installations, we focused our search on schools that had these micro-turbine systems implemented. Since Worcester Polytechnic Institute is a school, it would be greatly beneficial to see what systems were implemented by other schools, how they were implemented, and in what way were they used.

10.1 QUICK LOOK INTO SYRACUSE UNIVERSITY

In 2009, Syracuse University commissioned Capstone's technology using natural gas as fuel with a propane-air mixture backup fuel for the event of the natural gas system failing. The University uses 12 Capstone C65 Hybrid UPS microturbines as a combined cooling, heat and power source. The system uses 2 Thermax absorption chillers, a Cain Industries heat exchanger, a Validus high-voltage AC-DC reflector, and an EnerSys battery bank to carry the data center's maximum load for 17 minutes in the event of a rare catastrophic situation. ("Syracuse University" 1)

This data center is one of the most environmentally friendly in the world; designed to use 50 percent less energy and produce fewer greenhouse gases than other data centers of similar size. The hybrid UPS microturbine generates power while also using utility power to meet the demand of the electrical load. While meeting the electrical load requirements the system also satisfies the data center's heating and cooling demands. ("Syracuse University" 1)

10.2 QUICK LOOK INTO SALEM STATE COMMUNITY COLLEGE

Located in Carneys Point, New Jersey, Salem Community College commissioned 3 Capstone C65 ICHP microturbines used for heating, cooling, and power in 2009. The system uses a dual burner Thermax absorption chiller, a Capstone Advanced Power Server Controller to monitor the building's load changes and can also automatically shut down the most heavily used microturbines when they are not needed. ("Salem Community College" 1)

The 3 Capstone ICHP microturbines produce more than 80 percent of Davidow Hall's electricity as well as 100 percent of the building's heating and cooling every day. The system is stand-alone capable in the event of utility power loss, which allows the College to use the building as a Red Cross Disaster Relief Shelter. The college officials anticipate about a 30 percent energy savings. ("Salem Community College" 1)

10.3 East Hartford Case Study

To have a better understanding of an applied microturbine system, it was necessary to look into East Hartford High School (EHHS) due to its similar facility needs in comparison to Worcester Polytechnic Institute's. Along with their similar needs, East Hartford High School also has many knowledgeable years of cogeneration system operations.

Prior to implementing a Capstone microturbine system, East Hartford High School had a different but similar cogeneration system installed. However, after a fire destroyed the original and outdated turbine technology system, East Hartford High School used the insurance payout for a newer, greener cogeneration system. The High School determined that a Capstone Microturbine would be the best option due to the efficiency of the microturbine along with the company reputation.

To determine the correct size of the microturbine East Hartford High School determined the thermal load of the building. This thermal load is determined by the base load of the heating applications of the building including the hot water necessities and heating and cooling of the building. This can be determined by assessing a twelve month billing sequence. Once the base loads are determined, the electrical needs are to be determined as well. To find the electrical needs, it is vital to assess the hourly electrical usage over the course of the year. This helps to determine the correct base loads and peaks loads. It is important not to average the electrical peaks and base loads. This will result in a faulty assessment and lead to improper sizing of the microturbine.

The price range to install a system varies from about $250,000 to $450,000. These numbers fluctuate based on the size of the system, the location of the system, and if the building is under construction or if it is a retrofit project. This has been a well-invested overhaul at East Hartford High School. This four turbine system of 60 kW machines is due to payback for itself within the next couple of years. This system has pleased the folks at EHHS. The system allows for an enjoyable schooling experience because of the precise temperatures supplied to the facility and the less than zero hassle of downtown for maintenance. There have not been any failures with the machine. This system generates electricity for the entire facility and supplies the entirety of the heating for the buildings. By-and-large the Capstone microturbine system was a fantastic choice for East Hartford High School.

11 WORCESTER POLYTECHNIC INSTITUTE

As a school, Worcester Polytechnic Institute has a wide variety of goals pertaining to sustainability. But to understand those goals, one must first understand what is meant by the word sustainability. Sustainability reaches farther than just energy use alone in WPI's eyes, it extends to transportation, resource usage, and even recyclable material. In those regards, WPI works towards reaching a higher level of sustainability through academics, campus operations, research, and community engagement.

In terms of academics, there are many courses and research projects that take place on Worcester Polytechnic Institute's campus or are affiliated with WPI that are concerned with sustainability. "WPI's graduates will leave campus with the understanding and abilities to develop sustainable solutions to the world's problems" ("WPI Sustainability Plan" 6). This statement illustrates how WPI is motivated towards instilling a positive outlook on sustainability in all of its students by incorporating an understanding of the importance of sustainability. There is a very wide range courses, projects, and programs that address sustainability in one way or another at WPI. More than 90 courses offered at WPI address one or more aspects of sustainability (WPI Sustainability Plan 6). By instilling knowledge of sustainability in the lessons of the courses, WPI can help insure that its students are introduced to sustainability at one point or another while attending the institution. Of those many courses, there is the Great Problems Seminar. The Great Problems Seminar, or GPS as it's often referred too, is a program that first year students take where they engage in project work focusing on many issues. Of these issues that they learn of, there are Heal the World, The World's Water, Power the World, and Food Sustainability ("Sustainability: Campus Sustainability Report 2013" 6). This program is a great way to introduce sustainability ideas and concepts to new students at the start of their collegiate careers. Aside from the courses a student must take, there are also the IQP's and MQP's that are taking place year round. These forms of research are headed and advised by various WPI teaching faculty and cover a very wide range of topics. The way these research programs work is that professors have topics or projects they want researched and students apply to work on those projects. While both the IQP (Interactive Qualifying

Project) and MQP (Major Qualifying Project) are required for students to graduate from WPI, the MQP must be within the student's major field whereas the IQP is open to almost anything. Because of this, the IQP could be thought of as a way to widen a student's horizon by doing something outside of their field. In fact, over half the IQP's yearly deal with one form or another of sustainability (John Orr). These IQP's take place at various locations across the globe and deal with a wide spectrum of sustainability concepts. To take one IQP as an example, we can look at the Solar Decathlon in China. For this IQP, a team of WPI students joined students and faculty from Ghent University in Belgium and Polytechnic Institute of New York in China in the summer of 2013. The goal of this IQP was to promote the design of sustainable homes using solar technology. This project not only presented the WPI students with technical design challenges in sustainability, but also provided them an opportunity to collaborate on a multidisciplinary project with students and professors across the globe ("Sustainability: Campus Sustainability Report 2013" 7). As you can see, WPI is fully committed to incorporating their overall goal of sustainability into the curriculum of the courses. However, this is still only one part of the ways WPI is tackling sustainability.

"The operation of Worcester Polytechnic Institute's campus and facilities will demonstrate that the principles of sustainability guide our actions as well as our academic and research programs" (WPI Sustainability Plan 8). Making great strides to teach students about sustainability is a great tenant for WPI to live by, but that tenant would be hollow if the university itself did not exemplify what it teaches. Luckily, this is not the case as WPI goes to great leaps to apply its principles of sustainability to its campus. Like any college with a growing enrollment rate, WPI must match the growing student body with available space and adequate resources. WPI manages to do this with sustainable building practices, state regulations, and partnerships with utility providers ("Sustainability: Campus Sustainability Report 2013" 8). One sustainable building practice WPI has met for the past 10 years is the LEED certification. This is meeting a rating system for the design, construction, operation, and maintenance of green buildings developed by the Green Building Council. One of the most recent cases of these buildings would be the new residence hall, Faraday Hall. Finishing its construction this school year, this building features efficient plumbing, use of recycled materials, use of at least 20% less energy compared to a baseline case, and reaching a LEED Gold certification ("Sustainability: Campus Sustainability Report 2013" 11). Allocating resources is another crucial part to campus sustainability that WPI works for. Resources in this sense are energy, water, and even food. A great deal of thought is put in to finding ways become more sustainable with these resources. Despite the fact that WPI has had an increasing student population and number of buildings, there has been a steady decrease in total consumption of water since 2011 thanks to the efforts or installing new faucets, toilet "flushometers," and waterless urinals (WPI Sustainability Report 2013, 15). Providing energy and heat to the campus is a job that is done by WPI's Power House and is a constant source trying to become more sustainable. In May 2006, the Power House switched from oil to natural gas as its main fuel source. Since natural gas is a much cleaner burning and energy efficient fossil fuel, this greatly helped with WPI's energy source reaching a higher level of sustainability. Since then, WPI has been undergoing the process of making building renovations to improve insulation and switch from oil to natural gas in many of the buildings.

" Worcester Polytechnic Institute's students, faculty, and staff will be actively engaged in promoting a culture of sustainability to enhance the current and future welfare of our communities: on campus, in Worcester, for our nation, and globally" (WPI Sustainability Plan 12). Aside from teaching and displaying tenants of sustainability, WPI also promotes students and faculty taking part in the community to help spread the ideas of sustainability. This community is not just limited to the campus or even the city, but rather the entire planet. WPI has over 30 project centers around the globe that offer students opportunities to address issues in sustainability such as water quality, commercial development, affordable housing, and energy efficiency. Students at WPI can also take part in student organizations like Habitat for Humanity or Engineers Without Borders where they will take part in promoting sustainable change on and off campus. WPI offers a very wide and fulfilling variety of goals for sustainability that its faculty and students take part in on a regular basis.

11.1 Green Designs on Campus, the Impacts, and Future Designs

Worcester Polytechnic Institute has many green designs on campus that are constantly working towards making the school as a whole more sustainable. The Zip Car program is one green design, where students may rent out one of two fuel-efficient cars to use. By doing this, WPI is helping to cut down car emissions that would result from students driving less efficient cars. A few other green designs can be seen in one of the more new buildings, the Recreation Center. In the Rec Center, one can find many hands free hand dryers in the rest rooms that greatly help lower paper waste, waterless urinals and toilet "flushometers" that go a long way to reducing wasted flush water, and finally solar panels on the roof of the building that help heat the Olympic sized swimming pool on the basement floor of the building. While these last few designs are some of the most new and easy to see, there are many other green designs on campus that may be unseen but go a long way to improving campus sustainability. Updated lighting and heating for buildings go long ways to reducing lost heat or lowering electrical usage. Another green design on campus deals with reducing trash waste that the student and faculty body produce by being on campus. New garbage and recycling cans have been placed all around campus, giving easier access to recycling for the students and faculty, thus lowering trash waste that could have been recycled. These new cans also have been designed to be ascetically pleasing to the eye. While these designs all beneficially help lower costs or improve sustainability for the school, they also have another affect. These green designs can also be used to show off to prospective students the sustainable efforts the college is putting forth.

WPI also has many future goals and designs that have not yet been implemented. Plans for a cogeneration unit at one location in Gateway Park are currently underway. A new mandate for weekly food waste above 1 ton is being looked into. There are plans for updating the infrastructure of some older buildings on campus through renovations. The Task Force for Sustainability is currently under the process of hiring a new director, who will most likely bring his or her own plans for the direction of WPI's sustainability future. The future for sustainability at WPI looks bright and can only get brighter.

12 FEASIBILITY

The two buildings studied on Worcester Polytechnic Institute's campus were the main power plant and the Sports and Recreation Center. These two buildings were studied because of they were speculated as the two buildings with either largest electrical and thermal load or specific heating entities that would allow for an efficient usage of a microturbine.

The main power plant, originally run on oil-fired boilers now runs on natural gas. This switch was made to reduce the cost of producing the steam that heats the buildings. Twenty-three buildings are connected to the main steam line on campus. All buildings are connected together. This is important to note because all billing for the central power plant includes the heating expenses related to the twenty-three buildings. In addition, all electrical information for the twenty-three buildings is measured by one meter. This is very inefficient because data for each individual building cannot be assessed. Along the steam line is the Sports and Recreation Center.

The sports and recreation building was finished in 2013 and was designed with Worcester Polytechnic Institute's sustainability goals in mind. The Sports and Recreation Center was awarded LEED (Leadership in Energy and Environmental Design) certification for its environmentally friendly design and contribution to sustainability. The Sports and Recreation Center is equipped with green technologies such as the efficient windows, shades, and solar panels to help with the electric load.

There are certain criteria necessary in order for a building to qualify for cogeneration technologies. First on the list is whether the building has onsite natural gas. Natural gas is an important fuel source because of the high temperatures that it burns at increasing efficiency of a turbine. Also, natural gas is a more cost effective fuel source than oil. The next important qualification is in regards to the average electrical demand. The average electrical demand is based on the base loads of a building. The microturbine has optimum efficiency at one hundred percent load on the turbine. If the base load were larger than the assessed base load, the turbine will be inefficient and will not allow for a quick payback due to the amount of time the turbine would be offline. The next important necessity is whether the building has a central water system, and whether the building facilitates steam to produce hot water for heating and other hot water usages such as showers and faucets. Also needed is the appropriate space to install the machines. It is not necessary, but if the desire for emergency power is wanted for the building, a microturbine has the ability to meet this need. Important to the evaluation is the sustainability goal of the owners and operators of the building along with a desire for state incentives and LEED certification.

With all of these standards and qualifications in mind, we can evaluate the specific buildings. The power plant has natural gas fired boilers that create steam. This steam is looped through the system to specific buildings on campus. In the specific buildings, in our case the Sports and Recreation Center, steam boilers are used to heat the central water system for the showers and faucets. Solar thermal panels heat the Olympic style swimming pool located on the lower level of the gymnasium. The pool is the biggest energy consumer of the entire recreation center. (Mell, 1)

Everybuilding has on campus has a potential feasible application for a microturbine. There are a few different designs for the buildings. Before addressing the designs it is necessary to be familiarized with the different microturbines. In order to design a proper system it is necessary to assess the thermal loads first before looking at the electrical usage. The base thermal loads determine the size of the microturbine because of the therms given off by the system. Larger systems will give off a larger therm load than that of smaller systems. These loads will heat and cool the building where as the electricity will be generated constantly and can be used at disposal.

The central power plant, although would be able to run a microturbine to generate electricity and help with the reheat of the return steam to alleviate the work and natural gas used for the boilers, a system that is very large would need to be implemented and there is question of there not being enough space. The system would be nearly five hundred kilowatt turbine and require much more space than the smaller sized microturbines. However, the most important reason why the power plant is not an appropriate facility to install a microturbine is because the plant is shut down during the summer months. This drastically decreases the efficiency and payback of the microturbine. If space requirement is not an issue with the decision makers of Worcester Polytechnic Institute, then this would be a perfect location.

With the power plant on the backburner the focus is now on the Sports and Recreation Center. The microturbines chosen for our examination of the feasibility of the gymnasium are the Capstone C65 (65 kW) microturbine and the Capstone C30 (30 kW) microturbine both with cogeneration application. Because of the accessibility and cost effectiveness, the microturbine would run on natural gas. There are two different possible set ups for the recreation center.

The first set up calls for the smaller of the two turbines, the Capstone C30 with cogeneration application. With this set up, the Sports and Recreation Center would stay on the steam line. The microturbine would simply take the place of the pool heater in place now to keep the Olympic pool maintained at specific temperature. The turbine would also be able to supply the domestic hot water and with the implication of a heat absorber and chiller, the building would have air conditioning and heat if necessary.

The second set up would be the installation of the Capstone C65 with cogeneration application. Since the Sports and Recreation Center is on the steam line this size microturbine would be inefficient because it would exceed the base loads, thus resulting in an inefficient system. The only option is to install a bypass valve on the steam line. This would increase the base load to the summertime loads, as seen in the billing information, when the power plant is shut down. This would optimize the microturbine to be as efficient as possible.

13 FEASIBILITY ASSESSMENT

13.1 BREAKDOWN OF CAPSTONE MICROTURBINE

13.1.1 C65 kW CHP Capstone Microturbine

Actual output = 59 kW

Hours in one year = 8765.81 hours

Acceptable downtime leeway = 765.81 hours

Average hours run = 8000 hours/ year

1 Therm = 99,976.129 Btu

3 therm output

Electrical output in one month:

59 kW x 24 hours/day x 30 days/month = 42,480 kWh/ month

Electrical output in one year:

59 kW x 8000 hours/ year = 472,000 kWh/ year

Thermal Loads:

3 therms = 299,928.387 Btu

3 therms/hr x 24 hrs/day = 72 therms/day

72 therms/day x 30 = 2,160 therms/month

13.1.2 C30 kW CHP Capstone Microturbine

Actual output = 28 kW

Hours in one year = 8765.81 hours

Acceptable downtime leeway = 765.81 hours

Average hours run = 8000 hours/ year

1 Therm = 99,976.129 BTU

1.7 therm output

Electrical output in one month:

28 kW x 24 hours/day x 30 days/month = 20,160 kWh/ month

Electrical output in one year:

28 kW x 8000 hours/ year = 224,000 kWh/ year

Thermal Loads:

1.7 therms = 169,959.4193 BTU

1.7 therms/hr x 24 hrs/day = 40.8 therms/day

72 therms/day x 30 = 1,224 therms/month

13.2 Worcester Polytechnic Institute Data

The data seen has been extracted from the billing information located in the appendix.

13.2.1 Sports and Recreation Center

All data has been gathered using the bills located in the Appendix

NationalGrid Supply		
Electrical Usage		
March 13, 2013 to March 14, 2014		
	kWh	
Average	266,354	
Peak: Dec	317,000	
Demand - kW Peak	566	
off-peak	524	
For March 2014:		
Amount Due	$10,307.23	
Demand	249,000	kWh
Delivery Cost: Amt Due/Demand	**$0.041394**	/kWh

Direct Energy Costs (Third Party)		
For March 2014		
Amount Due	$18,717.33	
Demand	249,000	kWh
Third Party Cost:	**$0.07517**	$/kWh
Total Cost (Delivery + Third Party)	**$0.11656**	$/kWh

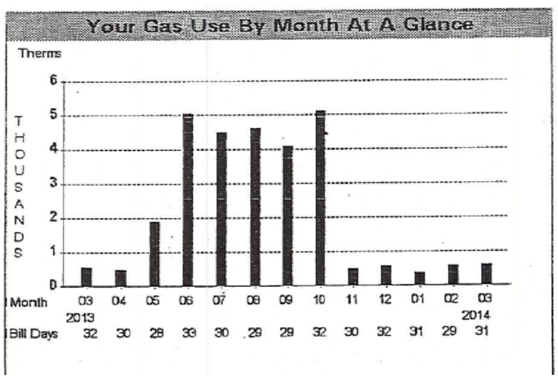
13.2.2 Central Power Plant

NationalGrid Supply		
Electrical Usage		
March 13, 2013 to March 14, 2014		
	kWh	
Average	1,490,031	
Peak: Aug	1,860,000	
July	1,776,000	
Demand - kW Peak	2,640	
off-peak	2,184	
For March 2014:		
Amount Due	$48,469.39	
Demand	1,240,800	kWh
Delivery Cost: Amt Due/Demand	**$0.039063**	/kWh
Direct Energy Costs (Third Party)		
For March 2014		
Amount Due	$93,270.94	
Demand	1,240,800	kWh
Third Party Cost:	**$0.07517**	$/kWh
Total Cost (Delivery + Third Party)	**$0.11423**	$/kWh

13.3 Worcester Polytechnic Institute and Capstone Feasibility Analysis

13.3.1 Recreational Center

Thermal Demands



Date	Therms
03/17	597
02/14	575
01/16	372
12/16	583
11/14	498
10/15	5116
09/13	4100
08/15	4626
07/17	4489
06/17	5035
05/15	1904
04/17	492
03/18	570

C65 kW CHP Capstone Microturbine

Electrical output in one month:

59 kW x 24 hours/day x 30 days/month = 42,480 kWh/ month

Electrical output in one year:

59 kW x 8000 hours/ year = 472,000 kWh/ year

Thermal Loads:

3 therms = 299,928.387 Btu

3 therms/hr x 24 hrs/day = 72 therms/day

72 therms/day x 30 = 2,160 therms/month

C30 kW CHP Capstone Microturbine

Electrical output in one month:

28 kW x 24 hours/day x 30 days/month = 20,160 kWh/ month

Electrical output in one year:

28 kW x 8000 hours/ year = 224,000 kWh/ year

Thermal Loads:

1.7 therms = 169,959.4193 BTU

1.7 therms/hr x 24 hrs/day = 40.8 therms/day

72 therms/day x 30 = 1,224 therms/month

To assess and size a proper microturbine it is essential to size the turbine using the thermal load of the facility. From Appedix M, we can determine a "peak base load" of 4,100 therms. In this instance, two C65 kW microturbines would be ideal. The base load for two would be 4,320 therms. The difference between would be a positive number. The two machines would supply a sufficient amount heat to quench the thermal usage. The peak is nearly 5,116 therms. The difference is nearly 1,000 therms which would cost a small amount, nearly double what is used when the power plant is running.

However, a single C30 kW CHP microturbine would be ideal. This machine allows for 1,224 therms. Even though this is a high number for the thermal usage while the power plant is running, the offset thermal could be used elsewhere in the building that the building does not buy gas from NSTAR for. This could be used to directly heat the pool and supply heating to the domestic water for showers and sinks. This is the ideal choice for the Sports and Recreation Center.

14 CONCLUSION

Through the methods of data collection and data assessment, it is concluded that a microturbine would be feasible on Worcester Polytechnic's campus. Although not a one-hundred percent efficient and one-hundred percent green technology, the microturbine has the ability to reduce WPI's carbon footprint and to keep WPI's sustainability goals moving forward. With the limited space on campus and around the desired buildings for green technology, the microturbine is small enough and powerful enough to produce desired thermal needs and electrical needs. Depending upon WPI's financial plans and outlook, the microturbine could be the perfect mechanical system to implement on campus. Rather than the power house, the Sports and Recreation Center is the preferred location for a microturbine.

The Sports and Recreational Center is connected to the steam line that supplies the necessary fluid for heating and cooling. This heating and cooling is not only for space temperature, but also for domestic water (faucets, showers, etc.). Another application is heating and maintaining pool temperature. It is a common misconception that the pool is heated by the solar panels on the roof. In reality, the solar panels simply offset the power needed to maintain the precise temperature of the water. If a power failure was to occur, the solar panels would not be able to hold the temperature at such an exact temperature causing the pool to fall below the minimum official Olympic swimming pool temperatures. This would cause an imbalance of chemicals leading to a possible draining of the pool if conditions were drastic. This is when a microturbine would be the most beneficial piece of equipment. The microturbine can operate as a standalone unit and would not be interrupted by the failure of utility power.

Since the Sports and Recreation Center is the newest building on Worcester Polytechnic Institute's campus, a complete retrofit would not be economically ideal. The best option between the two possible installments scenarios of the microturbine, would be to install a Capstone C30 kW CHP microturbine. Although a single C30 CHP cogeneration system is more expensive than the 60 CHP cogeneration system, it would be a better fit. The C30 system would take the solar panels offline, relieving them of their stress and duties to the facility. The C30 cogeneration system would heat the pool entirely and keep the pool in use and at a maintained temperature in case of a power failure. Along with heating the pool, the microturbine system would supply electricity to the building along with any desired domestic water heating and cooling, with the application of a steam boiler and an absorption chiller.

If there is interest in this technology by Worcester Polytechnic Institute's facility engineers, chief executive officers, and sustainability personnel, more information would need to be gathered in order to have an in-depth analysis of the building done by a professional in the field. The information needed for the in depth analysis would include two years of gas bills from both the utility supplier and third party provider and twelve months of bills from the electrical utility supplier and third party provider. The electrical usage of every hour in fifteen minute intervals over the period of 12 months would allow for a precise graphical analysis of the electrical peak and base load of the campus. These are the three main factors that would allow the Institute to determine the annual savings. This would help the Institute determine if it felt the microturbine is the sustainable way to go.

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16 APPENDIX

Appendix A: Direct Energy (Third Party) bill for Recreation Center

Direct Energy Business

Rec Center

Worcester Polytechnic Institute
100 Institute Road
Worcester, MA 01609-2220

MAR 31 2014

Account Number: 1156936
Invoice Number: 140820020606405
Billing Date: March 24, 2014
Page 1

ACCOUNT SUMMARY INFORMATION

Previous Balance	$23,588.35
Payment Received - Thank You	-$23,588.35
Adjustments	$0.00
Total Balance Forward	$0.00
Current Usage Charges	$18,717.33
Total Current Charges	$18,717.33
Total Amount Due	**$18,717.33**

Questions about your bill? Need a copy of your Terms of Service Document? Contact Direct Energy Business Customer Relations at CustomerRelations@DirectEnergy.com, or call us at 1-888-925-9115.

According to the terms contained in your energy service agreement with Direct Energy, if you end your service prior to the end of your agreement term, you may be charged an early termination fee. Please refer to your energy service agreement for details.

Congestion-related charges associated with accounts may be passed-through as per Paragraph 7 ("Price") of the Agreement with Direct Energy Business. Any noted congestion charge on your monthly bill is ESTIMATED and will be subject to an adjustment to reflect actual congestion charges.

We are pleased to offer free online and over the phone bill payment options. Visit our Customer Service Center at www.DirectEnergyBusiness.com to pay your bill online or 1-888-329-7906 to pay by phone.

Enroll in paperless billing today and help reduce your carbon footprint at business.directenergy.com/paperless.

Detach here and return this portion with check or money order. Do not staple or fold.

Direct Energy Business

Account Number	1156936
Due Date	May 7, 2014
Total Due	$18,717.33

Amount Enclosed $ 18,717.33

Please write your account number on your check or money order made payable to Direct Energy Business.

Worcester Polytechnic Institute
100 Institute Road
Worcester, MA 01609-2220

500000000000000115693620140507000187173333

Appendix B: Direct Energy (Third Party) bill for Recreation Center

Direct Energy Business

Account Number:	1156936
Invoice Number:	140820020606405
Billing Date:	March 24, 2014
	Page 3

YOUR SERVICE CHARGES

100 INSTITUTE RDSPORTS BUILDING, WORCESTER MA
EDC.# 6397861037 Store Number :
PO #:

Direct Energy Business
Electric Service
Meter#

Service Period February 19, 2014 to March 18, 2014 Actual-Total	445.39 kW UCAP	
Meter Multiplier of		
Meter# UNKNOWN		
Service Period February 19, 2014 to March 18, 2014 Actual-Total	249,000 kWh	
Meter Multiplier of		
February 19, 2014 to March 18, 2014		
Fixed Price - 249,000 kWh Total @ $0.07517/kWh	$18,717.33	
Current Actual Charges		$18,717.33

TOTAL CHARGES FOR EDC.# 6397861037 $18,717.33

Appendix C: NationalGrid utility bill for Recreation Center

Rec. Cent.

nationalgrid

MAR 28 2014

SERVICE FOR
WPI
100 INSTITUTE RD,
SPORTS BUILDING
WORCESTER MA 01609

BILLING PERIOD
Feb 19, 2014 to Mar 18, 2014

PAGE 1 of 2

ACCOUNT NUMBER	PLEASE PAY BY	AMOUNT DUE
63978-61037	Apr 13, 2014	$ 10,307.23

www.nationalgrid.com
CUSTOMER SERVICE
1-800-322-3223
CREDIT DEPARTMENT
1-888-211-1313
POWER OUTAGE OR DOWNED LINE
1-800-465-1212
EMAIL BILLING INQUIRES
customerservice@us.ngrid.com
CORRESPONDENCE ADDRESS
PO Box 960
Northborough, MA 01532-0960
ELECTRIC PAYMENT ADDRESS
PO Box 11737
Newark, NJ 07101-4737
DATE BILL ISSUED
Mar 20, 2014

ACCOUNT BALANCE

Previous Balance		13,367.16
Payment Received on MAR 17 (*ACH*)	*THANK YOU*	- 13,367.16
Current Charges		+ 10,307.23
	Amount Due ▶	$ 10,307.23

To avoid late payment charges of 0.82%, $ 10,307.23 must be received by Apr 13 2014.

➢ GO PAPERLESS: You'll help yourself and the environment by signing up to manage your bills online at www.nationalgridus.com/gopaperless.

Enrollment Information

To enroll with a supplier or change to another supplier, you will need the following information about your account:
Loadzone WCMA
Acct No: 63978-61037 Cycle: 14, WPI

Electric Usage History

Month	kWh	Month	kWh
Mar 13	208400	Oct 13	257000
Apr 13	295400	Nov 13	271800
May 13	205800	Dec 13	317000
Jun 13	238400	Jan 14	278400
Jul 13	274000	Feb 14	313800
Aug 13	293400	Mar 14	249000
Sep 13	260200		

DETAIL OF CURRENT CHARGES

Delivery Services

Type of Service	Current Reading	-	Previous Reading	=	Difference	x	Meter Multiplier	=	Total Usage
Energy	28461 *Actual*		27216 *Actual*		1245		200		249000 kWh
Peak	11566 *Actual*		11050 *Actual*		516		200		103200 kWh
Off Peak	16895 *Actual*		16166 *Actual*		729		200		145800 kWh
							Total Energy		249000 kWh
Demand-kW									
Peak							200		566.0 kW
Off Peak							200		524.0 kW
Demand-kVA									
Peak							200		574.0 kVA
Off Peak							200		532.0 kVA

METER NUMBER 04084023 NEXT SCHEDULED READ DATE Apr 21
SERVICE PERIOD Feb 19 - Mar 18 NUMBER OF DAYS IN PERIOD 27
RATE Time-of-Use G-3 VOLTAGE DELIVERY LEVEL 0 - 2.2 kv

Billed Demand Last 12 months

Minimum	468
Maximum	734
Average	602.1666

KEEP THIS PORTION FOR YOUR RECORDS.

RETURN THIS PORTION WITH YOUR PAYMENT.

nationalgrid

ACCOUNT NUMBER	PLEASE PAY BY	AMOUNT DUE
63978-61037	Apr 13, 2014	$ 10,307.23

PO Box 960
Northborough MA 01532

ENTER AMOUNT ENCLOSED
$

Write account number on check and make payable to National Grid

********ALL FOR AADC 015
WPI
OFFICE OF FACILITIES
100 INSTITUTE RD
WORCESTER MA 01609

049439

NATIONAL GRID
PO BOX 11737
NEWARK NJ 07101-4737

001030723 63978610378001030723103

Appendix D: NSTAR Gas bill for Recreational Center

NSTAR PO Box 660369, Dallas, TX 75266-0369

Account Number

12 7 0000022940 11 30 1594 463 0027 H

WPI
100 INSTITUTE RD
WORCESTER MA 01609-2280

MAR 26 2014

NSTAR Gas

Please Pay By: Apr. 6, 2014

Please Pay Amount: $229.40

Amount Enclosed

MOVING? PLEASE LET US KNOW. OTHERWISE YOU MAY BE RESPONSIBLE FOR ENERGY USE AFTER YOU MOVE.

Service Provided To:
WPI
100 INSTITUTE RD
WORCESTER MA 01609-2280

30 1594 463 0027 11

Gas Bill Comparison

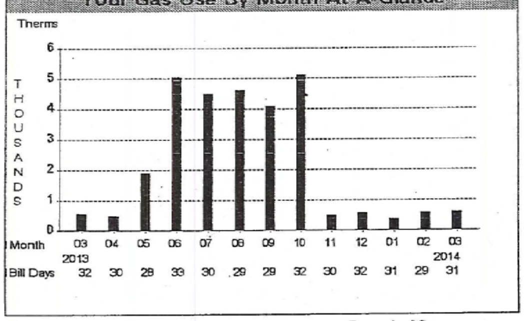
	Current Month	Last Month	Last Year
Gas Charges	$229.40	$222.05	$218.65
Total Gas Use (therms)	597	575	570
Delivery Charges (per therm) *Cost to deliver gas.*	38.4¢	38.6¢	38.3¢
Delivery Total	$229.40	$222.05	$218.65
Supply Charges (per therm) *Cost to purchase gas from AMERADA HESS*	**	**	**
Supplier Total	**	**	**

*** AMERADA HESS has elected to bill you directly for their charges.*

Bill Analysis

Billing Days	31	29	32
Avg. Daily Gas Use (therms)	19.2	19.8	17.8
Avg. Daily Temp (degrees)	27	23	34

Your Gas Use By Month At A Glance



5105

Page 1 of 2

Gas Bill Summary

Account Number	1594 463 0027
Please Pay By	**Please Pay Amount**
April 6, 2014	$229.40
Current Bill Date	**Next Meter Read Date**
March 19, 2014	April 16, 2014

Highlights From This Month's Billing Period

February 14, 2014 to March 17, 2014

Amount of Your Last Bill	$222.05
Payment - Thank You	-$222.05
Previous Balance	$0.00
Adjustments	$0.00
Delivery Charges Total	$229.40
Supplier Total	$0.00
Total Charges for Gas	$229.40
Please Pay Amount	$229.40

We've recently been notified you changed suppliers. You will now be billed directly by your new Supplier, HEM.

www.nstar.com

For Business Customers

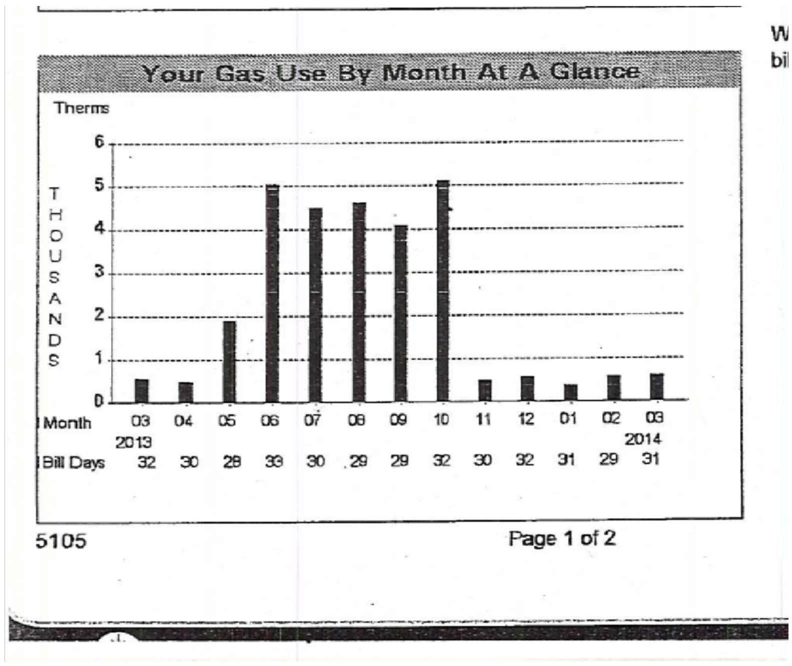
800-340-9822

Hours M-F 8:15 am - 4:45 pm

For emergencies and service interruptions please call 800-592-2000

Appendix E: NSTAR Gas usage by Month

This peaks of this graph show the months when the power plant is down (see Appendix L). The peaks are the highest usage of gas for the Recreation Center. The base loads from November to April is the data used to determine the thermal loads of the building during the school year.



Appendix F: Hess (third party) Gas bill for Recreational Center

HESS

MAR 26 2014

ACCESS YOUR INVOICES ONLINE AT WWW.HESSENERGY.COM

BILLING ADDRESS

Worcester Polytech Institute
Attn: William Grudzinski
100 Institute Road
Worcester, MA 01609–2280

Phone
1-800-HESS-AOK
(1-800-437-7265)

Fax
1-866-239-5671

Email
QCSTeam@hess.com

Web
www.hessenergy.com

Hours
Mon-Fri 8am-5pm

INVOICE INFORMATION

Invoice Date: 03/20/2014
Invoice #: H14191953
Payment Due Date: 04/04/2014
Payment Terms: Net 15 Days
Payment Method: Check

SERVICE LOCATION INFORMATION

Hess Account #: 452310/612674
Service Location: 100 Institute
WORCESTER, MA 01609

ACCOUNT INFORMATION

Utility Name: Commonwealth Gas Company
Pool/Point: TGP WOR DCQ
Utility Account #: 1594-463-0027-X000430

NEW CHARGES

Natural Gas Deliveries	Deal ID	Purchase Order #	Date From - To	Volume	UOM	Unit Price	Total
Commodity	1388077		02/15/2014 02/28/2014	273.5	THERMS	$0.8477	$231.85
Commodity	1388077		03/01/2014 03/17/2014	332.1	THERMS	$0.7775	$258.21

COM + BASIS =
5.557 + 2.92 = 8.477
4.855 + 2.92 = 7.775
HESS 605.6 THERM
NSTAR 597 THERM
Line 8.6 THERM
Loss

Total Charges: $490.06

Page 1 of 1

PLEASE TEAR AT PERFORATION AND RETURN WITH YOUR PAYMENT

THANK YOU FOR CHOOSING HESS AS YOUR ENERGY SUPPLIER

Customer Name: Worcester Polytech Institute
Hess Account #: 452310/612674
Invoice #: H14191953

Amount Due: $490.06
Payment Due Date: 04/04/2014

Check Remittance To:

Hess
P.O. Box 905243
Charlotte, NC 28290-5243

For Internal Use Only

Please Reference Invoice Number with Payment

Appendix G: Hess (third party) Gas bill for Power Plant

APR 0 7 2014 Hessenergy - Com → Gas Business cost-Info

HESS

ACCESS YOUR INVOICES ONLINE AT WWW.HESSENERGY.COM

BILLING ADDRESS

olytech Institute
am Grudzinski
ute Road
ster, MA 01609–2280

Phone
1-800-437-7265

Fax
1-866-239-5671

Email
QCSTeam@
DirectEnergy.com

Web
www.hessenergy.com

Hours
Mon-Fri 8am-5pm

INVOICE INFORMATION

Invoice Date: 04/03/2014
Invoice #: H14221428
Payment Due Date: 04/18/2014
Payment Terms: Net 15 Days
Payment Method: Check

SERVICE LOCATION INFORMATION

Hess Account #: 452310/465997 P.P.
Service Location: West St Stratton
WORCESTER, MA 01609

ACCOUNT INFORMATION

Utility Name: Commonwealth Gas Company
Pool/Point: TGP WOR DAILY
Utility Account #: 2736-580-0013-X000190

NEW CHARGES

Natural Gas Deliveries	Deal ID	Purchase Order #	Date From - To	Volume	UOM	Unit Price	Total
Commodity	1343407		03/02/2014 03/31/2014	15,629.34	MMBTU	$7.232	$113,031.39
Commodity	1343407		04/01/2014 04/01/2014	520.98	MMBTU	$6.961	$3,626.54

Dist. 2 → MA; stocks → TX
COM + BASES =
4.855 + 2.377 = 7.232
4.584 + 2.377 = 6.961
Hess 16,150.32 DTHM
161503.2 THERM
NSTAR 159226 THERM
LINE 2277.2 THERM
LOSS

Total Charges: **$116,657.93**

Page 1 of 1

PLEASE TEAR AT PERFORATION AND RETURN WITH YOUR PAYMENT

THANK YOU FOR CHOOSING HESS AS YOUR ENERGY SUPPLIER

Customer Name: Worcester Polytech Institute
Hess Account #: 452310/465997
Invoice #: H14221428

Amount Due: $116,657.93
Payment Due Date: 04/18/2014

Check Remittance To:

Hess
P.O. Box 905243
Charlotte, NC 28290-5243

For Internal Use Only

Please Reference Invoice Number with Payment

Appendix H: Direct Energy (Third Party) bill for Power Plant

Direct Energy Business

WORCESTER POLYTECHNIC INSTITUTE
OFFICE OF FACILITIES 100 INSTITUTE RD
WORCESTER, MA 01609

MAR 31 2014

Account Number:	1061578
Invoice Number:	140820020606398
Billing Date:	March 24, 2014
	Page 1

Questions about your bill? Need a copy of your Terms of Service Document? Contact Direct Energy Business Customer Relations at CustomerRelations@DirectEnergy.com, or call us at 1-888-925-9115.

According to the terms contained in your energy service agreement with Direct Energy, if you end your service prior to the end of your agreement term, you may be charged an early termination fee. Please refer to your energy service agreement for details.

Congestion-related charges associated with accounts may be passed-through as per Paragraph 7 ("Price") of the Agreement with Direct Energy Business. Any noted congestion charge on your monthly bill is ESTIMATED and will be subject to an adjustment to reflect actual congestion charges.

ACCOUNT SUMMARY INFORMATION

Previous Balance	$117,445.61
Payment Received - Thank You	-$117,445.61
Adjustments	$0.00
Total Balance Forward	$0.00
Current Usage Charges	$93,270.94
Total Current Charges	$93,270.94
Total Amount Due	**$93,270.94**

We are pleased to offer free online and over the phone bill payment options. Visit our Customer Service Center at www.DirectEnergyBusiness.com to pay your bill online or 1-888-329-7906 to pay by phone.

Enroll in paperless billing today and help reduce your carbon footprint at business.directenergy.com/paperless.

Detach here and return this portion with check or money order. Do not staple or fold.

Direct Energy Business

Account Number	1061578
Due Date	May 7, 2014
Total Due	$93,270.94

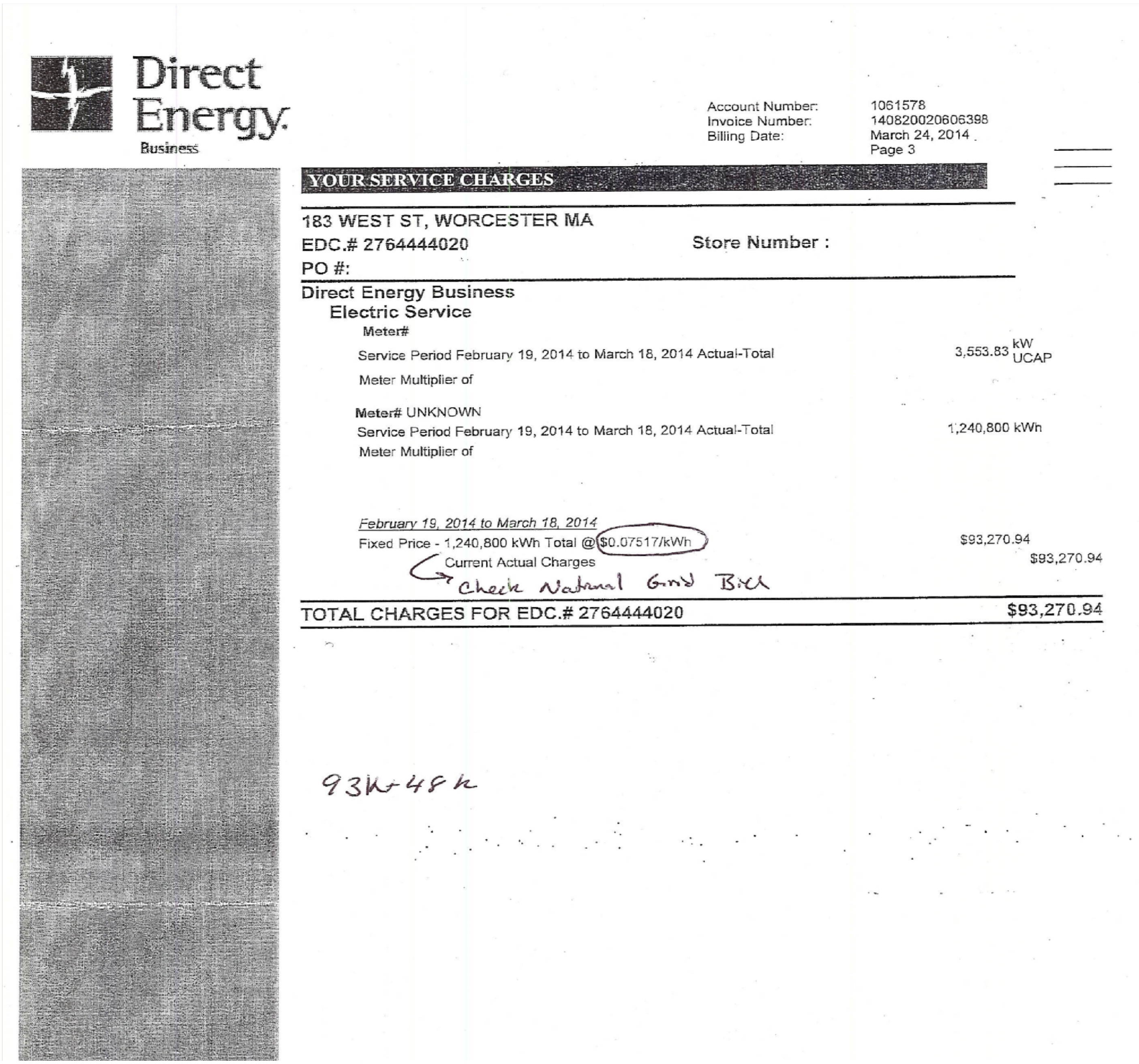
Amount Enclosed $ 93,270.94

Please write your account number on your check or money order made payable to Direct Energy Business.

WORCESTER POLYTECHNIC INSTITUTE
OFFICE OF FACILITIES 100 INSTITUTE RD
WORCESTER, MA 01609

500000000000000106157820140507000932709 47

Appendix I: Direct Energy (Third Party) bill for Power Plant



Direct Energy. Business

Account Number: 1061578
Invoice Number: 140820020606398
Billing Date: March 24, 2014
Page 3

YOUR SERVICE CHARGES

183 WEST ST, WORCESTER MA
EDC.# 2764444020 Store Number :
PO #:

Direct Energy Business
Electric Service
Meter#
Service Period February 19, 2014 to March 18, 2014 Actual-Total 3,553.83 kW UCAP
Meter Multiplier of

Meter# UNKNOWN
Service Period February 19, 2014 to March 18, 2014 Actual-Total 1,240,800 kWh
Meter Multiplier of

February 19, 2014 to March 18, 2014
Fixed Price - 1,240,800 kWh Total @ $0.07517/kWh $93,270.94
Current Actual Charges $93,270.94
Check National Grid Bill

TOTAL CHARGES FOR EDC.# 2764444020 $93,270.94

93k+48k

Appendix J: NationalGrid Bill for Power Plant

nationalgrid

MAR 2 8 2014

SERVICE FOR
WPI PLANT SERVICES
MAIN CAMPUS POWER
183 WEST ST
WORCESTER MA 01609

BILLING PERIOD
Feb 19, 2014 to Mar 18, 2014

PAGE 1 of 2

ACCOUNT NUMBER 27644-44020
PLEASE PAY BY Apr 13, 2014
AMOUNT DUE $ 48,469.39

www.nationalgrid.com
CUSTOMER SERVICE
1-800-322-3223
CREDIT DEPARTMENT
1-888-211-1313
POWER OUTAGE OR DOWNED LINE
1-800-465-1212
EMAIL BILLING INQUIRES
customerservice@us.ngrid.com
CORRESPONDENCE ADDRESS
PO Box 960
Northborough, MA 01532-0960
ELECTRIC PAYMENT ADDRESS
PO Box 11737
Newark, NJ 07101-4737
DATE BILL ISSUED
Mar 20, 2014

ACCOUNT BALANCE

Previous Balance		63,498.90
Payment Received on MAR 17 (ACH)	THANK YOU	- 63,498.90
Current Charges		+ 48,469.39
	Amount Due ▶	$ 48,469.39

To avoid late payment charges of 0.82%, $ 48,469.39 must be received by Apr 13 2014.

➢ GO PAPERLESS: You'll help yourself and the environment by signing up to manage your bills online at www.nationalgridus.com/gopaperless.

DETAIL OF CURRENT CHARGES

Delivery Services

Type of Service	Current Reading	-	Previous Reading	=	Difference	X	Meter Multiplier	=	Total Usage
Energy	68228 *Actual*		67711 *Actual*		517		2400		1240800 kWh
Peak	31206 *Actual*		30974 *Actual*		232		2400		556800 kWh
Off Peak	37022 *Actual*		36737 *Actual*		285		2400		684000 kWh
							Total Energy		1240800 kWh

Demand-kW		
Peak	2400	2640.0 kW
Off Peak	2400	2184.0 kW
Demand-kVA		
Peak	2400	2880.0 kVA
Off Peak	2400	2376.0 kVA

METER NUMBER 04848559 NEXT SCHEDULED READ DATE Apr 21
SERVICE PERIOD Feb 19 - Mar 18 NUMBER OF DAYS IN PERIOD 27
RATE Time-of-Use G-3 VOLTAGE DELIVERY LEVEL 2.2 - 15 kv

Enrollment Information

To enroll with a supplier or change to another supplier, you will need the following information about your account:
Loadzone WCMA
Acct No: 27644-44020 Cycle: 14, WPI

Electric Usage History

Month	kWh	Month	kWh
Mar 13	1207200	Oct 13	1627200
Apr 13	1706400	Nov 13	1305600
May 13	1288800	Dec 13	1492800
Jun 13	1420800	Jan 14	1296000
Jul 13	1776000	Feb 14	1562400
Aug 13	1860000	Mar 14	1240800
Sep 13	1586400		

Amount Due / USAGE = $/kwhr

Billed Demand Last 12 months

Minimum	2520
Maximum	3952.8
Average	3200.2

$ 0.03906 delivery cost / kwhr

KEEP THIS PORTION FOR YOUR RECORDS.
RETURN THIS PORTION WITH YOUR PAYMENT.

Does not include 3rd Party

nationalgrid

ACCOUNT NUMBER 27644-44020
PLEASE PAY BY Apr 13, 2014
AMOUNT DUE $ 48,469.39

PO Box 960
Northborough MA 01532

ENTER AMOUNT ENCLOSED
$

Write account number on check and make payable to National Grid

********ALL FOR AADC 015
WPI PLANT SERVICES
MAIN CAMPUS POWER
OFFICE OF FACILITIES
100 INSTITUTE RD
WORCESTER MA 01609

049434

NATIONAL GRID
PO BOX 11737
NEWARK NJ 07101-4737

March → Dist. + Util = 11.¢

004846939 27644440201004846939103

Appendix K: NSTAR Gas bill for Power Plant

Plant Gas.

NSTAR

Dallas, TX 75266-0369

MAR 28 2014

Account Number

21 30 2838 260 9999

WPI
OFC OF FACILITIES
100 INSTITUTE RD
WORCHESTER MA 01609-2280

NSTAR Gas

This Detail Bill Is for Your Records Only. Do Not Use this Stub for Payment.

RETURN THIS PORTION WITH YOUR PAYMENT. MOVING? PLEASE LET US KNOW, OTHERWISE YOU MAY BE RESPONSIBLE FOR ENERGY USE AFTER YOU MOVE.

Account Number	Billing Date	Next Read Date
2736 580 0013	Mar 4, 2014	Apr 1, 2014

Service Provided to

WPI
187 WEST ST PLANT
WORCESTER MA 01609

Account Summary

Previous Bill	108,670.17
Payment - Thank You	-52,460.67
Delivery Charges Total	50,940.93 ✓
Delivery Chgs Balance	**$107,150.43**

Gas Used

Rate 37-Commercial Heating
Meter X000190

Mar 01, 2014 Actual Read		624981
Feb 01, 2014 Actual Read	-	609339
		15642
Multiplied by Constant	X	10
CCF Used in 28 Days		156420
Times Therm Factor	X	1.0286
Therms Billed this Meter		160889

Date	Therms
03/01	160889
02/01	168937
01/01	163179
12/01	130506
10/31	51700
10/01	848
08/31	0
08/01	0
07/01	0
06/01	0
04/30	101382
04/01	143989
03/01	151718

Plant Down

Charges for Gas Used

Delivery Charges		
Customer Charge		100.00
Distribution	.21580 X160889 Therms	34,719.85
Distrib Adj	.10020 X160889 Therms	16,121.08
Delivery Charges Total		**50,940.93**

NSTAR

CUSTOMER SERVICE CENTER 800-592-2000
FOR BUSINESS CUSTOMERS 800-340-9822

Appendix L: Monthly Breakdown of Therms used at Power Plant

This is data shows the time the Power Plant is offline and does not supply the majority of the load to the Sports and Recreational Center.

Times Therm Factor X

Therms Billed this Meter

Date	Therms
03/01	160889
02/01	168937
01/01	163179
12/01	130506
10/31	51700
10/01	848
08/31	0
08/01	0
07/01	0
06/01	0
04/30	101382
04/01	143989
03/01	151718

Plant Down

NSTAR

Appendix M: NSTAR bill for Monthly Thermal usage of the Sports and Recreation Center

Monthly thermal use can be seen in the bottom left

NSTAR PO Box 660369, Dallas, TX 75266-0369

H

WPI
100 INSTITUTE RD
WORCESTER MA 01609-2280

DIGGING? HITTING AN UNDERGROUND WIRE OR PIPE CAN BE DANGEROUS. THAT'S WHY STATE LAW REQUIRES YOU OR YOUR CONTRACTOR TO CALL DIG SAFE AT 811 OR 888-DIG-SAFE AT LEAST THREE BUSINESS DAYS PRIOR TO DIGGING. FOR MORE INFORMATION VISIT WWW.DIGSAFE.COM.

VISIT THE "SAFETY" SECTION OF WWW.NSTAR.COM FOR MORE IMPORTANT SAFETY INFORMATION.

Account Number	Billing Date	Next Read Date
1594 463 0027	Mar 19, 2014	Apr 16, 2014

ervice Provided to

PI
00 INSTITUTE RD
ORCESTER MA 01609

Account Summary

Previous Bill	222.05
Payment - Thank You	-222.05
Delivery Charges Total	229.40
Delivery Chgs Balance	**$229.40**

Gas Used

ate 27-Commercial Heating
Meter X000430

lar 17, 2014 Actual Read		60041
eb 14, 2014 Actual Read	-	59461
CCF Used in 31 Days		580
Times Therm Factor	X	1.0293
herms Billed this Meter		597

Date	Therms
03/17	597
02/14	575
01/16	372
12/16	583
11/14	498
10/15	5116
09/13	4100
08/15	4626
07/17	4489
06/17	5035
05/15	1904
04/17	492
03/18	570

— Therms.

Charges for Gas Used

Delivery Charges

Customer Charge			30.00
Distribution	.22910 X	597 Therms	136.77
Distrib Adj	.10490 X	597 Therms	62.63
Delivery Charges Total			**229.40**

CHARGES ARE SUBJECT TO 0.82% INTEREST AFTER 25 DAYS.