The Truth About Photovoltaics

An exploration into the feasibility of bringing a photovoltaic array to Worcester Polytechnic Institute

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Acknowledgements

We would like to thank all the people that helped us develop this report. We would like to specifically thank Professor Alexander Emmanuel for advising and guiding us through our research process. We would like to thank Bill Grudzinski for his insight into what WPI has done and developing a plan suitable for WPI. We would also like to thank Mike Ortolano and Derrick Ajumni of Absolute Green Energy for going out of their way to offer their professional insight. We would also like to thank Professor Wanli Zhao for his economic insights and assistance.

Abstract

Solar power is an underutilized resource that can provide many benefits for WPI. A photovoltaic array at Worcester Polytechnic Institute could improve its standing in the community and provide funding for future endeavors. This report details a feasibility study that addresses the possibility of installing a photovoltaic array at WPI. Based on economic and environmental benefits, a recommendation was developed to place a 23kW photovoltaic array on the roof of Gordon Library. The photovoltaic system would consist of polycrystalline panels mounted using a ballasted system on the Gordon Library. This system would utilize micro inverters to reduce losses due to shading. The photovoltaic system is predicted to pay for itself in 6 years and generate over $100,000 in profit during the lifetime of the array. Financial calculations have shown that such a project would be a responsible decision for WPI.

Executive Summary

Solar power is an underutilized resource with great potential for clean energy generation. Photovoltaic arrays provide renewable energy while providing financial benefits for the owners. This report focuses on the feasibility of bringing such an array to Worcester Polytechnic Institute's campus. This work examined how a photovoltaic array installation could benefit WPI and created a fiscally responsible proposal.

This report was developed in collaboration with Bill Grudzinski, chief power engineer at WPI. Mr. Grudzinski expressed concerns about the lack of a photovoltaic system on campus. Concerns about building a photovoltaic array include the high initial investment and a long payoff period typically associated with photovoltaic installations.

Finding a financing option to fund the array was the next task. Research revealed several state and federal benefits available to WPI including a 30% federal tax credit and the sale of Solar Renewable Energy Credits (SREC's). An SREC represents one megawatt-hour of energy production by solar means, and can be sold to utility companies for an average price exceeding $500 in 2011 [11]. These benefits increase the economic feasibility of a photovoltaic system.

After reaching out to several companies (see appendix B), contact was made with Mike Ortolano, WPI alumnus and CEO of Absolute Green Energy in Worcester, MA. Work was completed in direct contact with Mr. Grudzinski and Mr. Ortolano to investigate possible locations for an array at WPI. This investigation revealed five buildings that would be adequate sites for a photovoltaic system. These sites are: Gordon Library, Daniels Hall, Morgan Hall, the Campus Center, and the Bartlett Center.

Building selection was based on several factors including the age and size of the roof, obtrusions on and around the roof, and the stability of the building. These factors were applied to each of the five buildings, and it was determined that The Gordon Library was the best location on campus for a photovoltaic array. The roof was recently replaced in 2008, meaning that the array can operate undisturbed for the full effectiveness of the array (25 years). The Gordon Library is a flat roof with a surface area of 16,500 sq. ft., meaning that a large ballasted system can be placed on top. Though the roof does contain a Heating, Ventilating, and Air Conditioning (HVAC) system, space for an array still exists. In a master's thesis completed in 2010 by Jamie Lynn Mayer, it was determined that The Gordon Library could support a photovoltaic array.

An array on the Gordon Library would be a positive influence environmentally and add to the school's reputation. The proposed 23 kW array would offset over 1.3 million pounds of carbon dioxide emissions over the 25 year lifetime. A photovoltaic system placed on the Gordon Library would be visible to the WPI community, and tracking data on the array could be displayed on monitors in the lobby. The educational benefits for WPI students would be real, since a photovoltaic system would offer a first-hand learning experience for students.

Arguably the most significant factor for installing a photovoltaic array is the required funding. Three primary options exist: a Solar Power Purchase Agreement (SPPA), an initial investment, or a payment plan. In a SPPA, WPI would serve as a host location to a photovoltaic system owned and operated by a separate entity. This option allows for WPI to receive green energy at a reduced cost with no investment required; unfortunately the financial benefits are minimal.

Paying for the array up front yields the greatest profit, though WPI would be required to pay a large initial investment. WPI has shown reluctance to investing capital, so this option is not recommended. A payment plan allows for a significant profit with no initial investment. Therefore, this is our recommended method for WPI to fund such a project.

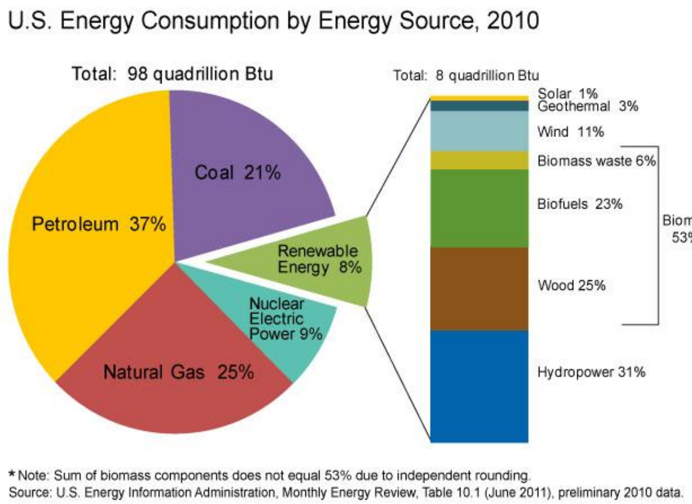
Economic calculations performed by the team show a realistic estimate for the outcome of the array. The system can be expected to generate a profit exceeding $100,000 over the 25 years of operation. Sensitivity analyses were performed to ensure an array would be responsible under varying circumstances. These analyses demonstrated the effects of changing values for electricity costs and SREC prices. The results of the analyses show that barring extreme circumstances, the array will net profit over its lifetime.

This plan presents an environmentally and financially responsible opportunity that will benefit all WPI community members, both present and future. This submitted plan has been achieved through collaboration with students, faculty and professionals.

Introduction

The majority of electricity production in the United States is derived from nonrenewable, unclean resources. The growing energy demand and increasing electricity prices are forcing consumers to seek alternative energy sources. Governor Deval Patrick has publicly advocated the implementation of renewable energy in Massachusetts, as demonstrated by Executive Order 484-Leading by Example. This order aimed to decrease energy costs of state buildings by adding green energy solutions [1].

With federal and state aid available, alternative energy projects are more viable than ever. Wind energy would create large visual obstructions, and hydroelectric generation is a poor option due to WPI's location. Solar energy remains the best possibility due to the availability and practicality of photovoltaic panels.



* Note: Sum of biomass components does not equal 53% due to independent rounding.
Source: U.S. Energy Information Administration, Monthly Energy Review, Table 10.1 (June 2011), preliminary 2010 data.

Figure 1: Energy consumption by various fuel sources [1]

Worcester Polytechnic Institute has allocated resources to Bill Grudzinski, chief power engineer, to research the feasibility of bringing a photovoltaic array to the campus. There are several buildings that have been considered for photovoltaics; however a feasibility study has never been proposed. While many agree that solar power could be an asset for the WPI community, the financing limitations have discouraged WPI's administration to install an array.

This report analyzes the factors that determine the adequate locations for a photovoltaic system and develop a suitable financing option for WPI. The goal of this report is to determine whether solar energy is a viable option and explore possible benefits to WPI. Previous studies have shown that photovoltaics are a viable option in Massachusetts (see appendix A, 15). This report demonstrates that completing such a project would be a responsible decision for WPI.

Background information

How fossil fuels affect the environment

Various sources of energy produce different levels of greenhouse gas emissions. Research was conducted on carbon dioxide (CO_2) emission data for various fuel sources including the production and disposal of conversion apparatuses.

Fossil fuels generate the highest CO_2 emissions. Coal produces an average of 992 grams of CO_2 per kilowatt-hour (kWh), while natural gas produces an average of 421 grams of CO_2 for every kWh of power generated. Nuclear power is much cleaner than fossil fuels, creating only 66 grams of CO_2 per kWh.

Solar and wind power produce less CO_2 in relation to fossil fuels. Solar energy creates on average 32 grams of CO_2 per kWh of power generation. Wind energy is the lowest at 16 grams of CO_2 per kWh, making both of these alternative energy sources environmentally friendly options. Compared to nuclear and fossil fuels, solar energy is an alternative way for a college campus to help the environment [2].

Global warming effect

Global Warming is a rising issue in today’s world. The main concerns stemming from global warming include the thinning Antarctic ice, increased temperature, extreme weather fluctuations, and rising water levels. A major factor of global warming includes excess carbon dioxide emissions due to unclean energy sources.

Across the globe, the overall temperature is increasing and disrupting established weather patterns. The Intergovernmental Panel on Climate Change (IPCC) has predicted an increase in size and frequency of heat waves, droughts, tropical storms, and tornadoes. If global warming keeps progressing at the current rate, these unusual weather trends will continue to grow in severity. Ice caps are melting around the world, ranging from Antarctica to the peak of Mount Kilimanjaro. In the Antarctic, most native life is dependent on the ice pack since it provides hunting and breeding grounds for local wildlife. As global warming continues, more species of animals will begin to dwindle until they are classified as an endangered species and eventually forced into extinction. [3]

Melting icepacks due to global warming increase the water levels of the oceans. This increase is threatening the coastal farmland in areas such as Florida and Maryland. The increased sea level is poisoning the ground and preventing future agricultural operations in these locations due to the increased salinity of the water. If this trend continues, damage to crops will compound. Global warming has affected several animal species by reducing the number of offspring they produce. Aquatic animals are the most heavily affected due to their sensitivity to temperature increases. An increase in temperature affects their migration routes, therefore reducing the number of aquatic animals that return to spawning grounds. The increased water temperature also negatively affects algae growth by changing their native environment. The decrease in algae diminishes the food supply for aquatic life. [4, 5]

What Makes Up a Photovoltaic Array

A photovoltaic array is comprised of three components; the panels, the mounting frame, and the inverter. The panels absorb sunlight, converting the solar radiation into electric energy. These panels are secured to a surface using a mounting mechanism. Inverters convert the DC voltage produced by the panels to AC voltage that can be used by buildings for lighting and running important systems.

Panels

For a project at WPI, there are three potential panels that can be used; monocrystalline, polycrystalline, and thin film. Monocrystalline and polycrystalline panels are the most common in the market due to their low cost and average efficiency. Monocrystalline solar cells are constructed of a single silicon wafer, making them brittle and more susceptible to manufacturing defects. This manufacturing process increases in the cost of the panels; however they achieve a 14% efficiency. Polycrystalline panels are constructed out of several sections of silicon wafers and do not succumb to the aforementioned shortfalls. These panels have an approximated 12% efficiency because they are comprised of smaller sections of silicon that are soldered together. Defective sections of polycrystalline panels can be replaced, and therefore are cheaper than monocrystalline.

Thin-film solar panels have a similar efficiency to silicon based panels; however these panels are constructed using different elements; specifically Cadmium and Tellurium. This results in a lower manufacturing cost when compared to silicon based panels. New technology has led to a recent increase in the efficiency of these panels (8%); however they still represent a small portion of the current market [6].

Polycrystalline panels are best suited for WPI due to several factors. They have a better efficiency to cost ratio than monocrystalline and thin-film panels and are used for most modern day arrays. With large, open areas, lower efficiency panels are used because they are less expensive. With buildings, space is limited and a higher efficiency is needed in order to make a decent profit [7].

Mounting Methods

There are two different types of mounting systems for panels. These include tracking panels which follow the sun during the day and static panels which are stationary. Tracking panels follow the path of the sun during the day and collect more sunlight per square foot than static panels. Tracking panels are more expensive and weigh more than static panels, and because they move they are more likely to break. Tracking panels may be more viable in the future, however in the current market the benefits of tracking panels do not make up for their disadvantages.

Static panels have two options including ballast and attached. A ballast system rests on top of the roof and use weights to make sure the array does not move. Ballasted systems increase the load on the roof, however are the simplest mounting system to install.

Figure 2: Photo of a ballasted array [8]

Attached systems are tied directly into a building. Attached arrays are lighter and can hold up better in worse weather conditions. Attached systems are usually installed when a new roof is installed as they may void warranties on current roofs. Attached systems cost more than ballasted system because they have to be tied into the building's structure.

Figure 3: Photo of an attached array [8]

Inverters

Photovoltaic panels produce DC voltage and convert it to AC voltage using an inverter. There are two types of inverters: central and micro inverters. A central inverter takes the output from panels and converts it into AC voltage, while micro inverters convert the output of each panel individually. A central inverter is a less expensive option, however they cannot cut off panels that are shaded and therefore are more susceptible to these decreased efficiencies as predicted in Figure 5. Micro inverters operate panels independently, allowing panels that are shaded to be cut off from those in sunlight. This causes the efficiency of the array to remain nominal despite some panels being shaded.

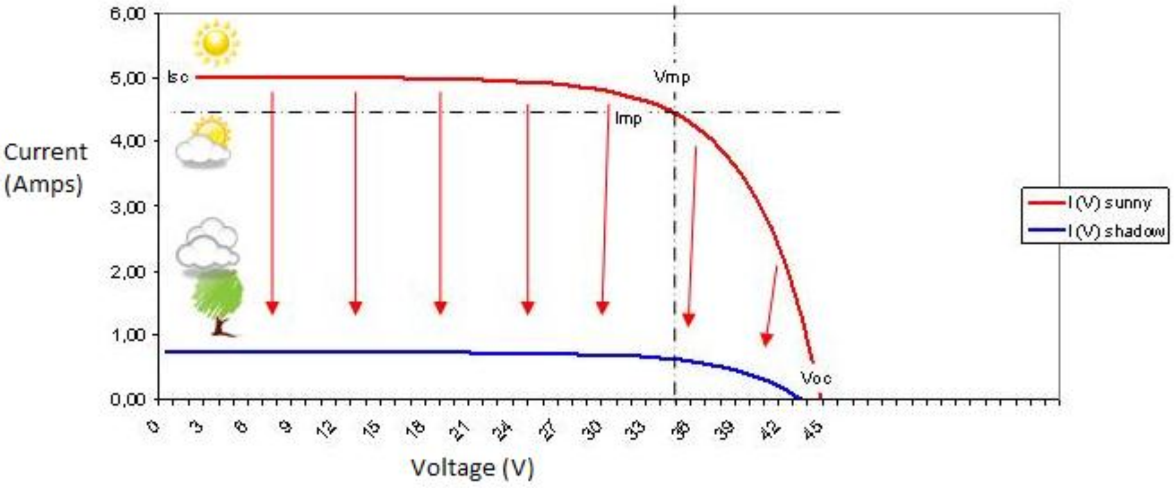


Figure 4: Chart comparing the power outputs of a sunny array and a shaded array [9]

Battery vs. non-battery system

When installing a photovoltaic array, the system can either be connected to a battery or tie directly to the building. A battery system is a good residential option for households that want to be completely off the grid. The battery is charged during the day, while the stored power is used during the night. A system without a battery sends all generated power to the building; any excess is fed back into the power grid. The utility company will reimburse the owner of the system for this power.

For WPI, a non-battery system would be ideal. The amount of power generated from the array would not be able to exceed the amount used by the campus. If there is no excess power generated, then there is no need for a battery system to be installed. Photovoltaic power generation coincides with the time for peak electricity during the day, resulting in increased savings. This increase in savings is attributed to the higher cost of electricity during peak hours.

Executive order 484 – Leading by example

In 2007, newly elected Governor of Massachusetts Deval Patrick issued Executive Order 484 – Leading by Example. The goal of the executive order was to create incentives for state buildings to use renewable energy sources. The order stems from the Division of Capital Assets Management (DCAM) which created goals for state buildings to reach by the year 2012. These initiatives are:

- 25% reduction in greenhouse gas emissions from 2002 levels
- 20% reduction in energy consumption of state buildings from 2004 levels
- 15% of energy consumption procured from renewable energy sources (either through purchase of renewable energy or through installation of on-site resources)
- 10% reduction in water use from 2006 levels

The initiative also targeted buildings with large roof areas in hopes of installing large scale renewable energy solutions to applicable buildings. All of these initiatives are to be carried out by DCAM [10].

Worcester State College

Worcester State College, a member school of the Worcester Consortium, installed a photovoltaic array on their campus in 2009. An interview was conducted with Mr. Bob Daniels, the head of facilities at Worcester State College. Mr. Daniels is involved in retrofitting the campus using a range of aspects, from eliminating trays in the cafeteria to installing the solar panels on top of their learning resource center and library building. This interview provided a first-hand description of how the solar installation at Worcester State College could apply directly to a solar installation project at WPI.

How Worcester State became involved

After Governor Patrick decided to allocate funds to install photovoltaic arrays on state buildings, he needed locations for these installations. Governor Patrick sent out a call to state sites to volunteer their locations to become part of Executive Order 484. Several of these locations include Springfield Technical Community College, Soldiers Home, and Worcester State College. In 2009, Worcester State College volunteered their library and learning resource center for such a project [11].

About the photovoltaic array at Worcester State College

The array at Worcester State College is located on top of their library and learning resource center. The panels take up roughly 33,000 square feet of rooftop space, creating an array with 105 kW of peak power generation. The panels are mounted at a fixed angle of 25 degrees to collect sunlight. Because of the lack of obstructions on and around the building, the solar window is measured between 98% and 99%. Another factor that had to be examined was whether the building could support the weight of an array. The original blueprints for the building had plans for an extra floor, meaning that the additional weight from the panels would be a non-issue.

Figure 5: The Array at Worcester State University [12]

After deciding upon an appropriate location for a photovoltaic array, the equipment and installation costs were the next concern. The total cost for the array was $850,000; however there are many state and federal options that subsidize this value. State energy bonds made up $310,000 of the upfront cost. This is a zero interest payment plan lasting 15 years. Worcester State College pays back around $20,667 each year for the next 15 years while the array brings in an estimated $25,000 each year in energy savings. The school earns an estimated net profit of $4,333 each year. The difference of $540,000 was paid for by the Massachusetts Technology Collaborative, a group which helps pay for the initial cost of solar panels for state organizations.

After the 15 year period, the college retains all savings from the array. The efficiency factor of the panels is guaranteed to be at least 90% after 10 years and 80% after 25 years. The inverter for an array of this size costs between $70,000 and $80,000 and it is expected that it will need to be replaced after 10 years. Since the array generates an estimated $25,000 per year, the replacement cost can be offset by the energy savings generated by the array.

While the facilities department at Worcester State College monitors the power generation from the panels, outside companies are utilized to run and maintain the system. Worcester State College purchased panels from Evergreen Solar and Gro Solar was contracted to install and maintain the array.

Tracking information on Worcester State College's array is available online [11]. Since the system was installed in August 2009, trends relating to energy production have emerged. Summer months have been shown to have higher energy production due to more direct sunlight and less snow cover. This effect can be seen in Figure 6: . According to Mr. Daniels, the amount of power generated is higher than the predicted values when the photovoltaic system was designed.

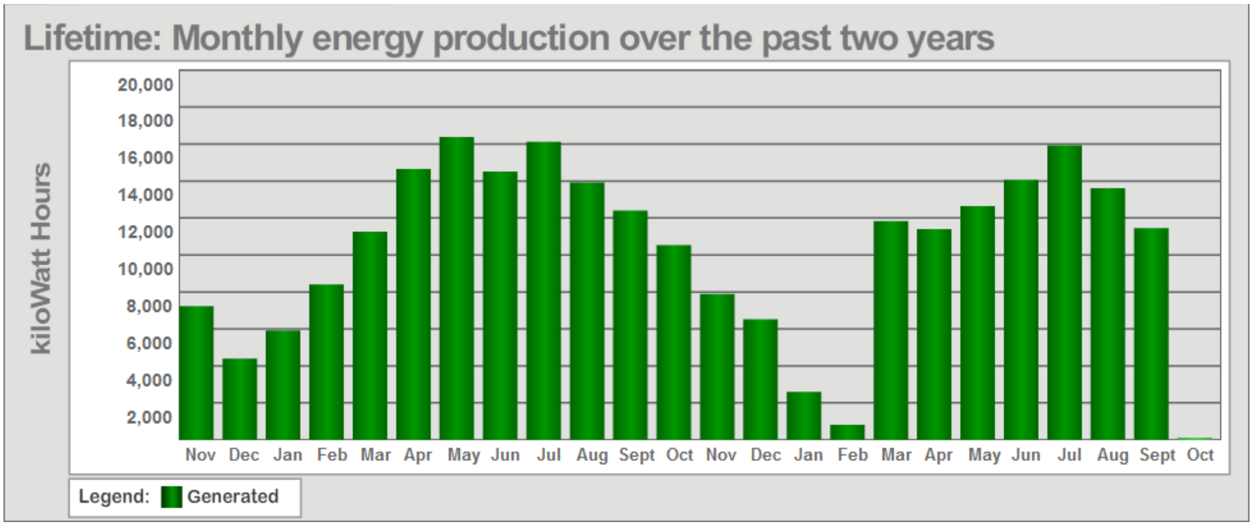


Figure 6: Energy production 11/2009-09/2011 [13]

One of the issues that Worcester State encountered was related to snowfall. While their array has a 12 inch clearance from the rooftop, any additional slow accumulates on the surface of the panel. The snow hits the panel and is held up by the snow just below it on the slope. This creates a thin layer of snow that covers the panel and severely reduces the sunlight exposure. This effect is shown in February of 2010, where the amount of power generated is greatly reduced in relation to the other months. One theoretical solution that Mr. Daniels of Worcester

State came up with was attaching a heating strip at the base of each panel. This would remove the snow accumulation, allowing for greater exposure to sunlight. [14]

This process is shown in the figures below. Figure 8 is a side view of a panel mounted on a roof. Figure 9 shows snow that is below the clearance of the panels. This does not dampen the panels in regards to energy generation. Figure 10 shows the effect of accumulated snowfall over the clearance of the panels. A thin layer of snowfall is suspended on the surface of the panel. Increasing the clearance of the mounts would make the panels more susceptible to wind and reduce the safety of the mounting system.

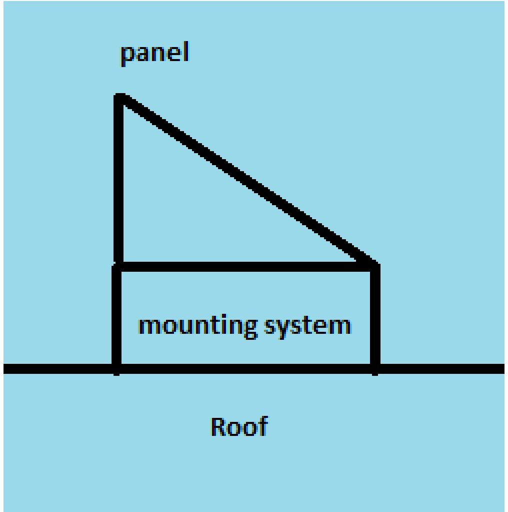


Figure 7: Side View of Solar Panel

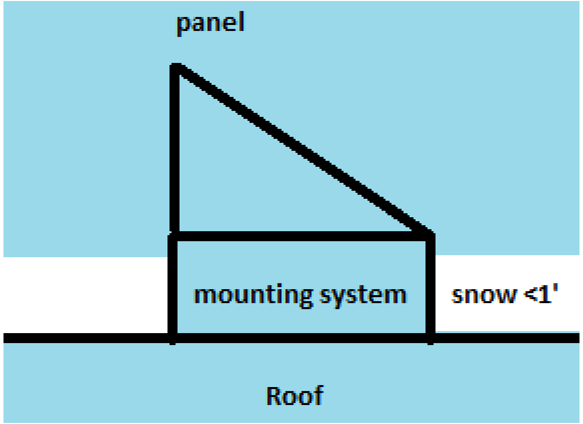


Figure 8: Side View of Solar Panel with Snow Below Clearance level

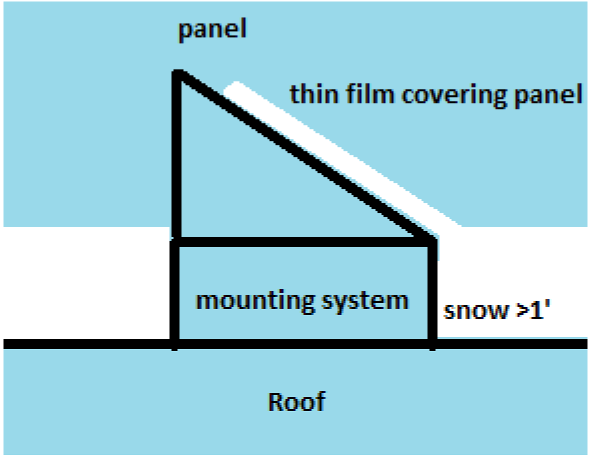


Figure 9: Side View of Solar Panel with Snow Accumulation

What WPI has done

Citizens Energy Report

In 2007, WPI contacted Citizen's Energy to conduct an energy audit of its campus. The proposed agreement with Citizen's Energy was to design and construct photovoltaic systems in various locations on campus. An outside company would own and operate an array located on WPI's campus, providing energy to the campus at a rate comparable to National Grid.

WPI decided not follow through with the energy audit at this time, as disagreements between WPI and the Citizens Energy team led to an incomplete audit of the campus. Though WPI would be a host to a photovoltaic array, there would be little financial benefit to the college.

While the plan proposed by Citizen's Energy was not completed, the partial audit revealed some useful information including factors used for determining viable locations for an array. Important factors for potential sites include a southern facing roof, limited shading, the usable area, and structural durability of the buildings. After examining several of the buildings, Citizen's Energy determined four buildings on campus that would be appropriate locations for installing a photovoltaic array. Locations of the recommended buildings are highlighted in Figure 11.

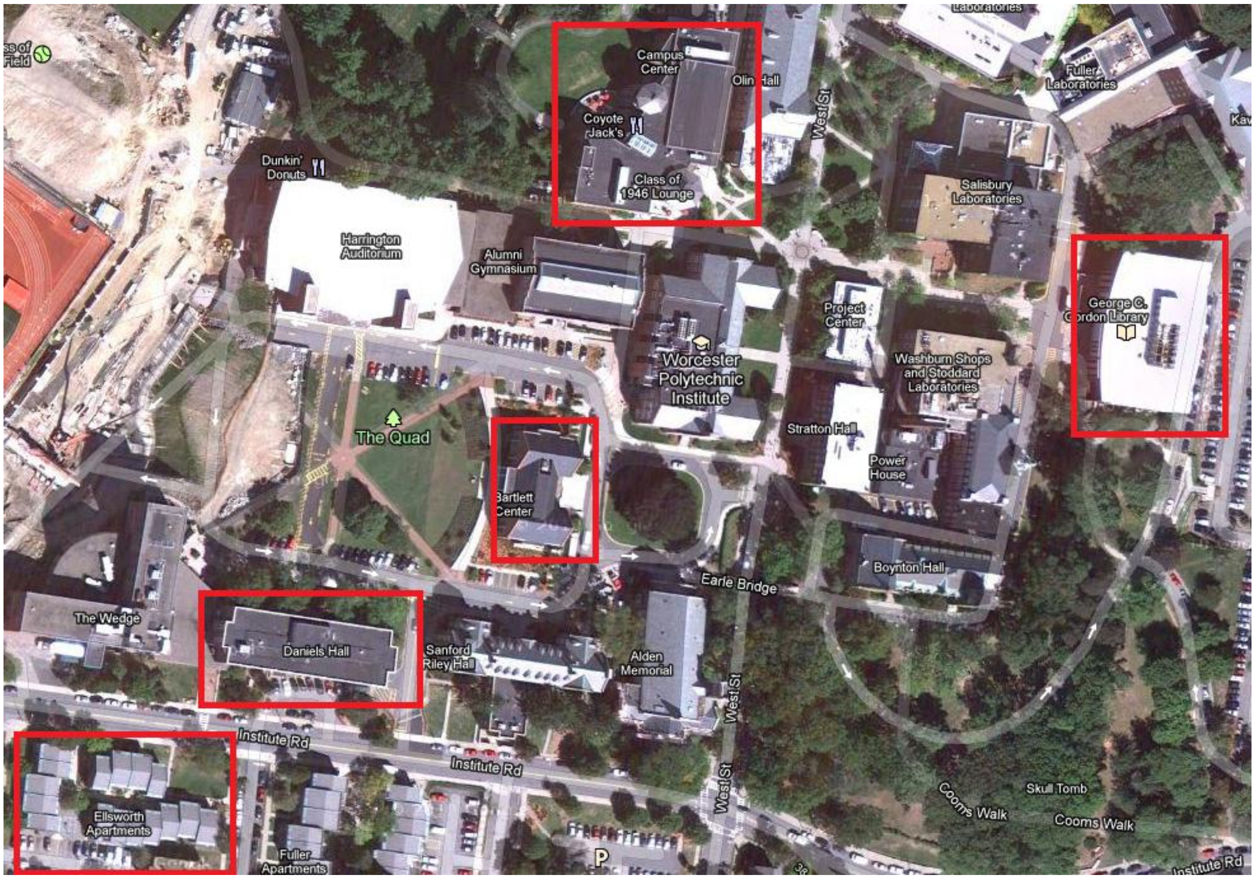


Figure 10: Citizens Energy Recommended Buildings [15]

Two proposed sites included the residence halls Daniels Hall and Ellsworth Apartments. These buildings could support the weight of a photovoltaic array while providing ample power generation. Daniels Hall has a flat roof, allowing for a simplistic mounting support to collect the optimum amount of sunlight over the course of a day. The estimated yearly energy generation for Daniels Hall was around 62,000 kWh. For the Ellsworth apartments, the panels would only be installed on the south facing sections of the roofs. The mounting system would be parallel to the roof and therefore an angled support system would not be necessary. An array on Ellsworth Apartments would yield an estimated 19,000 kWh per year.

Figure 11: Google Earth image of Ellsworth Apartment rooftop [15]

Figure 12: Google earth image of Daniels Hall rooftop [15]

The other two buildings selected by Citizen's Energy were the Campus Center and Gordon Library. Like Daniels Hall, the supports on the roof of the Campus Center would be angled so that the panels would collect the optimal amount of direct sunlight. The estimated yield for the Campus Center is roughly 37,000 kWh per year. The last location selected was the Gordon Library. The large Heating, Ventilation, and Air Conditioning (HVAC) system on the roof shades certain areas and limits the amount of usable space for solar power generation. This array would still provide a substantial amount of energy to the school, with an estimate of 122,000 kWh per year for the total production.

Figure 13: Google Earth image of Campus Center rooftop [15]

Figure 14: Google Earth image of Gordon Library rooftop [15]

Mayer's Thesis: Solar on the library

In 2010, a thesis titled Design of a Rooftop Photovoltaic Array for the George C. Gordon Library at Worcester Polytechnic Institute: Structural, Thermal, and Performance Analysis was submitted and presented by Jamie Lynn Mayer that describes the possibility of placing a photovoltaic array on the roof of the Gordon Library at WPI. Mayer's report included details about the various arrays available in the current market, compared the chemical differences between arrays, and also the mounting methods. The report compared three types of photovoltaic modules, three tilt angles, two orientations, and two mounting methods in order to predict the ideal setup for WPI.

Mayer’s results suggested that the CdTe (Cadmium Tellurium) – based panels were the ideal choice. The mathematical models suggested that a mounting angle of $27°$ from the surface oriented $-8°$ from South would produce the highest level of efficiency based on our geographical location. In addition to the efficiency models, the thesis computed stress analyses on the solar panels for the most common weather conditions to ensure limited damage to the panels. She found that the ballasted panels were heavy and unstable in some weather conditions, and may be an unnecessary risk to the project. Attached systems provided better results, withstanding most weather hazards with the exception of wind-propelled 2-inch hail. The attached systems were also significantly lighter than the ballasted system, providing less risk to the structural integrity of the library.

Projected values of the project were impressive and optimistic, estimating an output of 27,000 kWh a year and offsetting 56,000 pounds of CO_2 emissions annually. This thesis indicates that the solar array would be a realistic option for WPI, paying for itself in 18 months. It is important to note that Mayer utilized four benefits to reduce the upfront cost including grants from the U.S. Department of Treasury, U.S. Department of Agriculture, the Massachusetts Solar Stimulus, and the 30% federal tax credit. The grants are no longer available, however they have been replaced with SREC credits. Because of these changes, an updated financial analysis was necessary to accurately predict the cost and saving of a photovoltaic array [16].

Buildings for solar

Deciding where to put solar

There are several factors that are considered when installing a photovoltaic array. The selected site must be able to support an array, have an adequate solar window, and have a newly resurfaced roof. All of these characteristics must be met before an array can be built.

Supporting the building

One of the major issues with installing solar is whether or not a photovoltaic array can be supported by the roof. A commercial scale photovoltaic array (50 kW or larger) requires a professional engineer to verify that the building is in accordance with Massachusetts Building Code [17]. Mayer’s thesis contained a thorough stress analysis of the building and verified that the weight would not compromise the structural integrity. The proposed array was less than 50 kW, and therefore would not require an inspection by a professional engineer.

Solar Window

The solar window is described as the percentage of the day that the panel receives sunlight. Anything under 80% is too inefficient to be considered a responsible investment. Any shaded areas of the array decrease the overall efficiency because a shaded panel has a higher resistance than one that is in direct sunlight; this higher resistance reduces the power generation of the photovoltaic system.

Rooftop age

The age of a rooftop is critical for determining the effectiveness of a solar array. The traditional lifespan of an industrial roof is 30 years, while the lifetime of a solar array is 20-25 years. The optimal timeframe to install a photovoltaic array is within the first 5 years of a new roof. Attached systems require penetration into the roof surface and may void the warranty; therefore it is recommended that such a system is installed in conjunction with a new roof. Due to removal, storage, and reinstallation costs, the lifetime of the photovoltaic system should coincide with that of the roof.

Photovoltaic array sites at WPI

WPI hosts a variety of buildings on its diverse campus. These buildings vary in age, size, and rooftop layout, which are vital when selecting buildings to put a photovoltaic array on. Rooftop size is a key factor when considering the impact a photovoltaic array would have on campus. The usable surface area of the roof is a major factor, and sometimes only a fraction of the rooftop is available for photovoltaics. Obstructions such as HVAC systems also limit the possible size of a photovoltaic system. Level roofs can utilize angled supports, while pitched roofs can only incorporate south facing surfaces.

An examination of the buildings at WPI revealed several viable locations for a photovoltaic array. The Bartlett Center has potential because the pitched roof is at an ideal angle for solar power generation; however their small size would not generate a significant amount of power for the school.

There are several large buildings on campus that would allow for a greater size array and produce more energy for the campus. Buildings such as Salisbury Labs and Washburn Labs have large areas, however would not be able to support the weight of an array. Morgan and Daniels Hall would have a large area; however the amount of obtrusions limits the usable surface area.

Another option for WPI would be a parking lot array. A structure would be erected such that each parking space in a parking lot would be covered by a solar panel. These arrays are not impeded by rooftop obtrusions and generally have high solar windows. The panels can also protect the cars below the panels from weather conditions such as rain and snow. A logical choice for this would be the Gateway Parking Garage because of the strong structure and the high solar window. Installing an array on top of Gateway Parking Garage would be good for the environment and power generation however the array would not be visible from the campus. Gateway Parking Garage would require a specialized frame to support the panels, increasing the installation cost.

Method for calculating solar

There are several set values that can be used for a preliminary solar economic analysis; this allows for the estimation of cost and profit of a photovoltaic system. By inserting known values such as the usable area, the cost of electricity, and the SREC value, key characteristics for an array can be determined.

The first factor in measuring the amount of solar power generation is the usable area for the array. This determines the number of panels that can be used and therefore the overall power generation of the array. The amount of usable space is limited by obtrusions in the area. There are software programs (such as Google SketchUp) that companies have that determine which areas receive direct sunlight 80% of the time and are deemed usable.

Usable area (ft^2) = area with at least an 80% solar window

This area can be converted into the peak output (kW) of the array. Polycrystalline panels can generate 8 to 10 watts peak power per square foot [18]. 8 watts per square foot was assumed for analysis as to limit the possibility of overestimation of power generation. By multiplying this number by the usable area the peak power output the array will produce is calculated.

Area (ft^2) x 8 x 10^{-3} (kW/ft^2) = array size (kW)

The upfront cost can be calculated from the array size. The value Absolute Green Energy uses to estimate the upfront cost is $5.50 per watt. This covers designing the array, cost of the panels, and the installation. By multiplying this number by the size of the array, we can estimate the cost that WPI would have to pay.

Cost of array = size of array (W) x $5.50 (dollars/W)

One of the benefits for solar power is a federal tax credit that equates to 30% of the upfront cost. This is available for a photovoltaic array that is equal or less than 1 MW (1,000 kW) [19] and helps to increase the profit generated over the lifetime of a photovoltaic system.

Tax credit (dollars) = 0.3 x initial upfront cost (dollars)

Initial Payment (dollars) = 0.7 x initial upfront cost (dollars)

The next step is to calculate the amount of power generated by the panels during a given year. The key factors in determining this are the size of the array and the efficiency factor of the panels. The amount of power generated each year under ideal circumstances is the product of 1.221 and the size of the array. This experimental constant is from Absolute Green Energy and used for calculation purposes [17].

Ideal energy generated (kWh per year) = 1.221 x size of array (kW)

The efficiency factor of the panels will decrease over time; however panels are guaranteed to be operating at certain efficiency at 10 and 20 years. At year 10, the minimum efficiency factor of the panels is 95%, and is 90% at year 20. Efficiency factors during the other years have been extrapolated and are listed in the financial spreadsheet (see Appendix C). The following equation is used to calculate the actual power generation.

Actual energy generation (kWh for year Y) = ideal energy generation (kWh) x efficiency factor for year Y

To determine the savings for an array during a given year, an important factor involves the cost of electricity. The product of the amount of power generated and the cost of electricity per kWh determines the savings for a photovoltaic array. This report estimated $0.11/kWh, an average cost of electricity for peak and off-peak hours [20].

Energy savings for year Y (dollars) = Energy generated (kWh) during year Y x cost of electricity/kWh (dollars/kWh)

Another important number from a financial standpoint is the number of SREC's earned. Since 1 SREC equates to 1 MWh of energy generated, the number of SREC's earned in a year is equal to the amount of energy generated (in kWh) divided by 1,000.

Number of SREC's = Actual energy generated (kWh) / 1,000 (kWh/SREC)

These SREC's are valuable because they can be sold and increase the profit for an array. As of September 2011, the average SREC in Massachusetts sold for $525/SREC [12]. By taking the number of SREC's generated and multiplying by the average price (assumed $500 for this calculation as a safe estimate), the additional profit for the array can be determined.

SREC profit (dollars) = Number of SREC's x Average SREC price (dollars)

All of these equations relate to how WPI would fund an array. The loan would be paid for using the energy savings and the profit earned from SRECs. This value is typically higher than the minimum loan payment required, and should repay the loan in less than 10 years.

Loan payment (dollars) = Energy savings (dollars) + SREC profit (dollars)

Our calculations show the loan would be paid off in 6 years by using the energy savings and SREC profit. This means that WPI could potentially have 19 years of energy savings and 4 years of SREC profit. The savings could be reinvested into the student curriculum and other school endeavors.

Attached in Appendix C is an excel spreadsheet designed to calculate these values based on roof area, the cost of electricity and the value of SREC credits. The example demonstrates the calculated values for an array utilizing 1,000 square feet of usable space, a cost of 11 cents per kWh, and an average SREC value of $500.

Specific buildings at WPI

The team selected four buildings at WPI as suitable sites for an array. These buildings are the Gordon Library, Campus Center, Bartlett Center, and Daniels Hall. The following are summaries on each building with key numbers and important characteristics about each building. In appendix C are spreadsheets that provide an in-depth look to the key financials about each building.

Gordon Library

Figure 15: Gordon Library Roof Top [21]

Square foot of roof: 16,500 ft^2

Size of array: 23 kW

Year roof was installed: 2008

Panel selected: Polycrystalline

Inverter selected: Micro inverter

Mounting system: Ballast

Total upfront cost (before benefits): $126,500

Total upfront cost (after Federal Tax Cut): $88,550

Number of SREC credits earned over lifetime: 275

Payoff Period: 6 Years

Internal Rate of Return: 14%

Carbon dioxide offset over 25 years: 1,395,854 lb.

Total profit over 25 years: $104,835

Spreadsheets detailing these numbers and additional characteristics are available in appendix C.

Other notes on array:

Despite having a large rooftop area, the total usable space for an array is reduced due to a large HVAC unit in the center of the roof. There are additional features that would make the library a good selection; the white roof diverts heat from the panels, while the rubber material would be ideal for supporting the pressures created by a ballast system. The library roof is also visible from several buildings on campus and could be an important discussion topic for tour groups. A continuous readout for energy generated, carbon dioxide offset, and other environmental characteristics could be displayed on one of the library monitors located at the entrance to the building.

Campus Center

Figure 16: Campus Center Roof Top [15]

Square foot of roof: 18,000 ft^2

Size of array: 20 kW

Year roof was installed: 2001

Panel selected: Polycrystalline

Inverter selected: Micro inverter

Mounting system: Ballast

Total upfront cost (before benefits):$110,000

Total upfront cost (after Federal Tax Cut): $77,000

Number of SREC credits earned over lifetime: 239

Internal Rate of Return: 14%

Total profit over 25 Years: $88,552

Carbon dioxide offset over 25 years: 1,213,786 lb.

Spreadsheets detailing these numbers and additional characteristics are available in appendix C.

Other notes on array:

While the array would not be visible from other locations on campus, it would be at a central location. The array would not be excessive in size, meaning that the upfront cost would be reasonable. The irregularities and obstructions on the roof cause the size of the array to be reduced dramatically. The age of the roof (10 years as of 2011) is a major concern as it may need to be replaced before the full potential of a photovoltaic system is achieved.

Bartlett Center

Figure 17: Bartlett Center Roof Top [15]

Square foot of roof: 7,800 ft^2

Size of array: 12 kW

Year roof was installed: 2007

Panel selected: Polycrystalline

Inverter selected: Micro inverter

Mounting system: Attached

Total upfront cost (before benefits): $66,000

Total upfront cost (after Federal Tax Cut): $46,200

Number of SREC credits earned over lifetime: 143

Total profit over 25 years: $45,131

Internal Rate of Return: 12%

Carbon dioxide offset over 25 years: 728,272 lb.

Spreadsheets detailing these numbers and additional characteristics are available in appendix C.

Other notes on array:

The Bartlett Center is a difficult building to put a photovoltaic array on. The severe slope of the roof means that the array would have to be attached, increasing the upfront cost. Only two of the slopes are oriented correctly for an ideal array. Prospective students would see the array immediately as they visited the campus, which could be a big image boost for the school.

Daniels Hall

Figure 18: Daniels Hall Roof Top [15]

Square foot of roof: 11,750 ft^2

Size of array: 22 kW

Year roof was installed: unknown, approx. 1980-1985

Panel selected: Polycrystalline

Inverter selected: Micro inverter

Mounting system: Ballast

Total upfront cost (before benefits): $121,000

Total upfront cost (after Federal Tax Cut): $84,700

Number of SREC credits earned over lifetime: 263

Total profit over 25 years: $99,407

Internal Rate of Return: 14%

Carbon dioxide offset over 25 years: 1,335,165 lb.

Spreadsheets detailing these numbers and additional characteristics are available in appendix C.

Other notes on array:

Morgan and Daniels Hall provide an adequate location for a solar array. The age of the roof means that an array installation and roof replacement could be completed simultaneously. There are several HVAC systems located on the roof of the building that may interfere with the array, thus the reason for the micro inverter instead of a central inverter.

Recommendation for WPI

After our research and collaboration with Absolute Green Energy, we have created a plan of action for Worcester Polytechnic Institute. We have determined that the Gordon Library is an ideal location for a photovoltaic array due to its large solar window, visibility on campus, the structural integrity of the building and the condition of the roof. Polycrystalline silicon panels will be used for their cost effective nature as well as the resilience to shading. The array will be attached using a ballasted system, as the library can sustain the added weight, the roof will not be damaged, and a ballasted system is more cost effective than an attached system. Micro inverters are chosen rather than one central inverter because micro inverters are capable of managing shading issues likely to arise from the HVAC system on the library roof.

Another option for WPI is to install all four of the proposed arrays. The combined photovoltaics arrays would amount to a 77 kW system that would generate nearly $400,000 in profit over the lifetime of the arrays. By increasing the size of the array, the Internal Rate of Return also increases to 15%. This shows that while the cost will be linear, the earnings are not. The financial calculations utilized to generate this analysis are contained within a spreadsheet in Appendix C.

Financials behind solar

Why Massachusetts is good for solar

There are several state and federal resources to aid solar projects in Massachusetts. These programs are designed to increase the number of photovoltaic arrays by making them financially viable for residents of the state. There are benefits that can be directly applied to an array installed at WPI and make solar energy a fiscally responsible option for the school.

Federal tax credits are provided to those funding solar projects in an attempt to encourage photovoltaic array installation on a more frequent basis. The tax credit equates to 30% of the total project cost. WPI could use these tax credits toward a photovoltaic system on campus and generate more profit over the lifetime of the array.

In the state of Massachusetts, a renewable portfolio standard requires power companies to produce 5% of their total energy using renewable resources. This is regulated by the number of renewable energy credits (or REC's) the company owns. If a company does not produce enough green energy on its own, it must buy additional REC's to supplement the difference. These REC's are distributed to those who generate energy using renewable sources.

REC's are sorted into different classifications that vary based on generation method. Solar Renewable Energy Credits (SRECs) are earned for operating a photovoltaic array. These SRECs represent 1 megawatt-hour of energy produced by solar means. Each SREC may be sold through the state auction, and the prices of the market are determined by supply and demand. While auction prices may vary, minimum and maximum values are enforced; the minimum price per SREC is set by the federal government at $285. The average value varies, though in 2011 this value was $525.

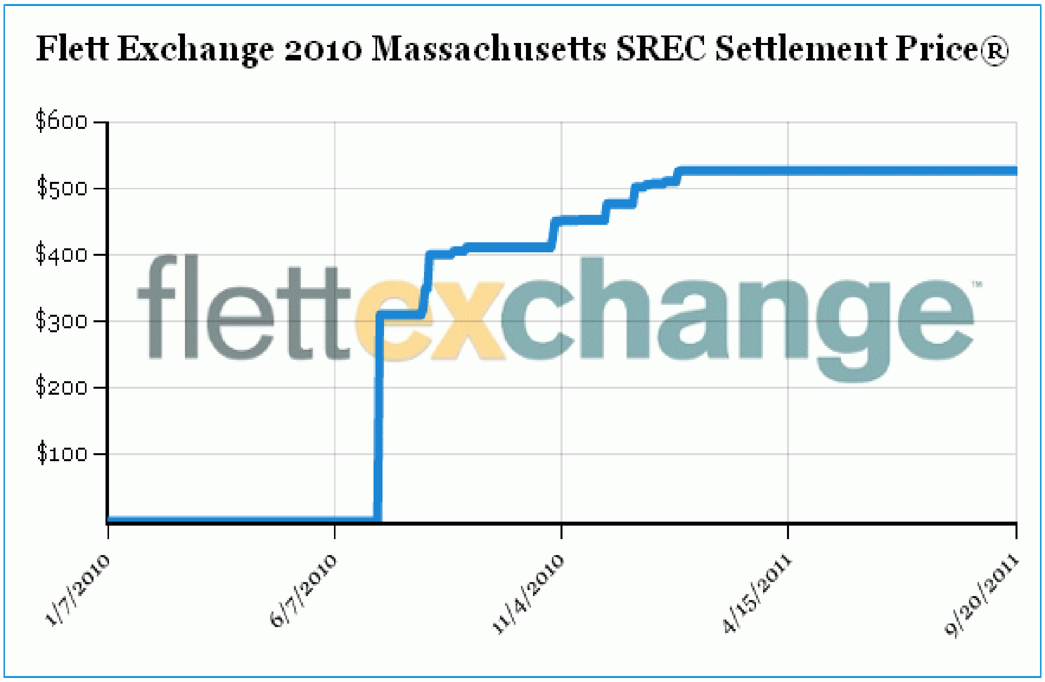


Figure 19: SREC Pricing Trend [22]

It is important to note that these SRECS are sold in an open market, so prices will vary over time, even on a month-to-month basis. In 2010 the monthly prices varied by up to $75 per SREC, though the price never dropped below $500 [23]. Utilities are required to provide a total number of REC’s, and if this number is not sufficiently met then a payment must be provided to the state, known as Alternative Compliance Payment (ACP). This ACP was set to a specific value by the Solar Carve Out program in Massachusetts, though this rate may be lowered by up to 10% a year. This lowered ACP does not necessarily mean that the average Price of an SREC will fall with it, though it is a possibility [24].

Payment options

A primary concern with installing a photovoltaic array is funding such a project. One option that WPI can utilize is a Power Purchase Agreement. A Solar Power Purchase Agreement (SPPA) is a contractual agreement between multiple parties to deliver solar power at an affordable cost.

An SPPA would allow WPI to act as a host site for a third party to build and operate a photovoltaic array. While the array would be located on WPI’s main campus, the array would not belong to the institution. This array would deliver energy directly to WPI’s buildings at a competitive rate payable to the owners of the array [19, 25, 26, 27]. This plan was recommended by Citizen's Energy in their partial audit listed in Appendix D.

Another payment option for installing a photovoltaic array is paying for the array upfront. This means that WPI would front the initial cost for the array and earn profit on SREC sales and energy savings. This option yields the most money for the college; however WPI has expressed reluctance to commit capital to such a project. This reluctance is the primary reason that an array has yet to be installed on campus.

The third option for WPI is a 10 year payment plan. This is an ideal option because there would be no upfront investment on WPI's behalf, and the institution would still own the array. Our analysis on the library shows that WPI can install an array for no upfront cost and pay off the loan in less than 10 years. This confirms that WPI can earn a net estimated profit of $104,000 over 25 years with no initial investment.

Lifetime cost of the array

After the initial cost, maintenance must be performed to ensure that the array functions well over its lifetime. This includes preventative maintenance and the replacement of the inverter for the array. Because the recommended array is a ballasted system with no moving parts, the preventative maintenance is minimal. The inverter is the most significant maintenance cost for any photovoltaic array as they must be replaced around the 10 year mark. Replacing the inverter can be delayed an additional 2 to 3 years to increase the lifetime of the array to 25 years.

Disposal of an array

A key factor in determining the value of an array is the depreciation of the panels. The calculations account for full depreciation over the 25 years, meaning that the panels have no value after 25 years. Because the lifetime of modern solar panels is 25 years and the field of photovoltaics is still developing, a disposed panel market has yet to fully develop.

Most photovoltaic panels are comprised of highly recyclable materials. Some of these materials include glass, aluminum, and a semiconductor material (such as Cadmium, Tellurium, or Silicon). Companies including First Solar have developed a process to recover materials in CdTe panels. By the end of the recycling process, 90% of the glass and 95% of the semiconductor materials can be recovered. Any recovered value from recycled panels will generate additional profit for the array [28].

Financials spreadsheet explained

The financial spreadsheets for each building were created with help from Absolute Green Energy. The spreadsheets take several inputs and calculate several key values including total profit and payoff period. An explanation of all the spreadsheet parameters and how they affect our results is listed below.

Project details

System size (Watts DC): The peak amount of power the array can generate. This number is used to quantify the size of arrays.

Annual expected production (kWh): The estimated amount of energy an array will produce in one year.

System Cost: This is the total upfront cost to install an array. This number is calculated before Federal and State credits are accounted for. Purchase and installation of an array can be estimated at $5.50 per watt [17].

Initial payment: The initial capital required to install a photovoltaic array.

Federal Grant: A tax credit granted by the federal government which equates to 30% of the initial cost of a photovoltaic array.

Net Cost: The amount that WPI would have to pay after the federal grant.

Average SREC price: The average selling price of SREC's in Massachusetts.

System Performance

Efficiency factor: The relative efficiency of the panels; in relation to their peak power output

Energy Production (kWh/year): The energy produced in a given year.

Energy savings ($): The estimated savings in electricity from photovoltaic power generation instead of purchasing from the grid.

Estimated SREC's: The estimated number of SREC's earned by the array. SREC's are available during the first ten years of operation.

Estimated SREC income: The amount of money earned for selling SREC's in Massachusetts.

Total income: The amount of money earned over the lifetime of the array. This includes the energy savings profits from the sale of SRECS.

Loan remainder: The amount of principle remaining on the loan.

Loan payment: The amount of money WPI pays each year to pay off the loan.

Yearly profit: The amount of profit the array generates for WPI each year.

Payoff Period: The time it takes for the array to pay for itself.

Internal Rate of Return: The yearly profit described as a percentage of the initial investment.

Sensitivity Analysis

Although the financial calculations demonstrated in Appendix C are important, research into non-ideal conditions was necessary. Calculations involving SREC prices and the cost of electricity use current market values; these values are likely to change during the 25 year operation of the proposed system. Several sensitivity analyses were completed to show the effects of these changing values.

SREC's are a significant source of income for WPI. Because these SREC's generate such a high percentage of the array's net worth, a sensitivity analysis was imperative. The net profit has a positive linear correlation with SREC value as shown in Figure 21.

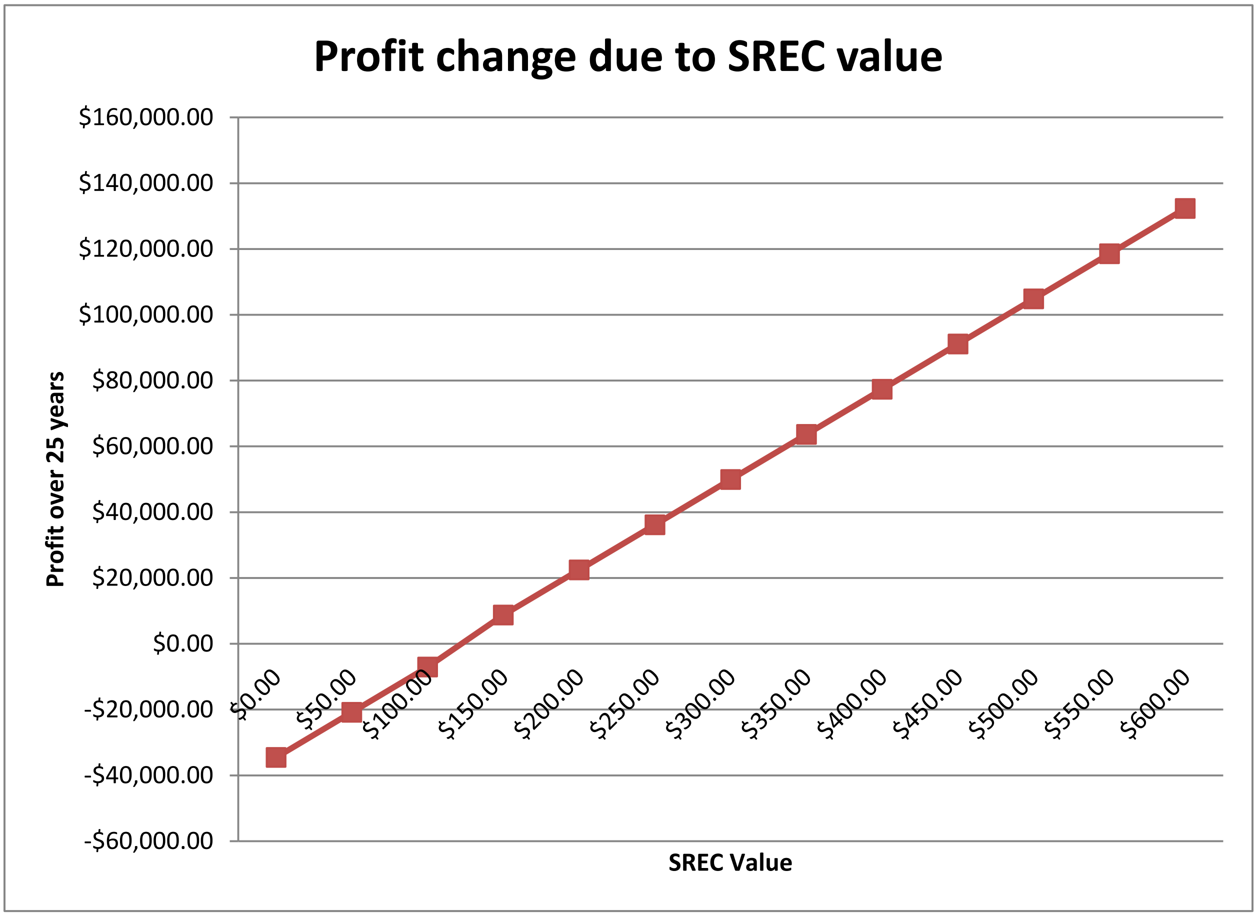


Figure 20: Profit change vs. SREC Price

This figure shows that if electricity prices remain constant the array will generate a net profit as long as the average SREC price stays above $125. As of 2011, the federal minimum SREC sale price is $285. The current average SREC price is $525 [12] and appears to be stable as shown in Figure 20. Current trends suggest that net loss due to changing SREC prices is unlikely.

The price of electricity is another fluctuating variable to be analyzed. The total profit of the array is directly related to the price of electricity. Electricity produced by the array is subtracted from the electricity purchased by WPI, reducing the total bill. As electricity prices increase, the profit from the array increases. This result is shown in Figure 22.

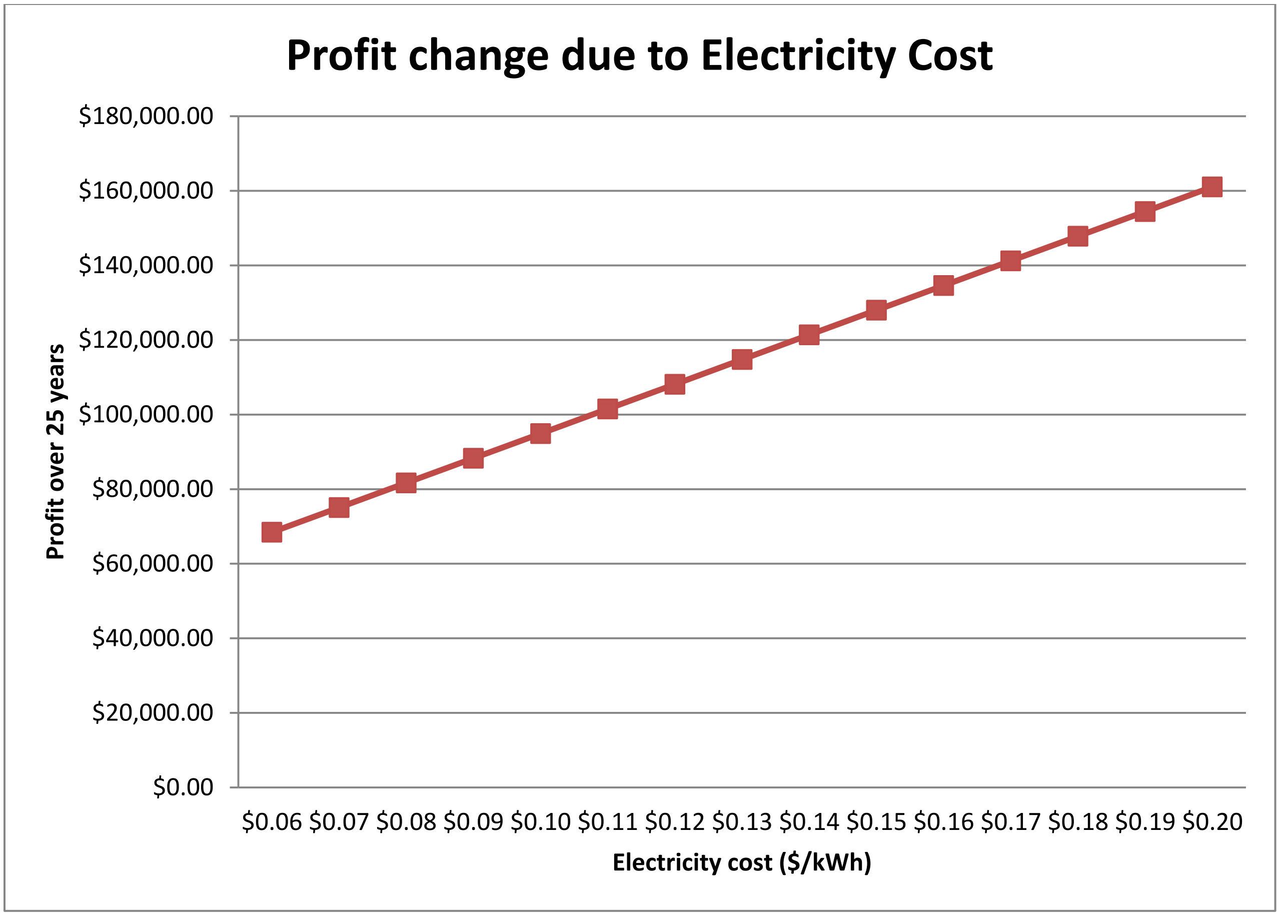


Figure 21: Profit change vs. Electricity rates

Due to inflation and other factors, the cost of electricity is expected to increase over the next 25 year [20]. Our analysis assumed $0.11/kWh, however an increased from this value is a safe assumption. An increase in the cost of electricity would generate more profit for the owner of an array.

The one-variable analyses are important, though the most important analysis involves examining both variables at once. Figure 23 is shown below demonstrating this analysis.

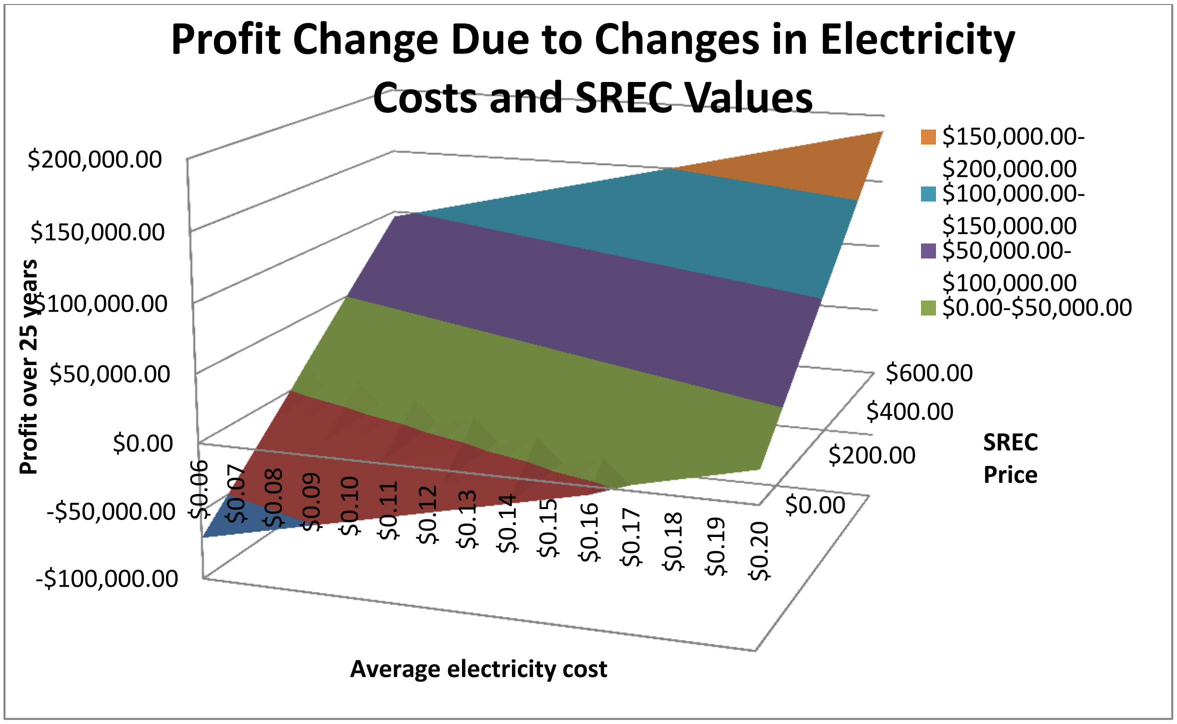


Figure 22: 3-Dimensional Sensitivity Analysis of Profit

The profit generated by the array varies based upon the price of electricity and the value of SRECs. Figure 23 demonstrates the high likelihood of the photovoltaic array generating a net profit. The figure also shows that SRECs have a greater effect on the profit than the cost of electricity. Net loss occurs only when the value of an SREC drops below the federal minimum value of $285, showing that the array will generate profit under reasonable circumstances.

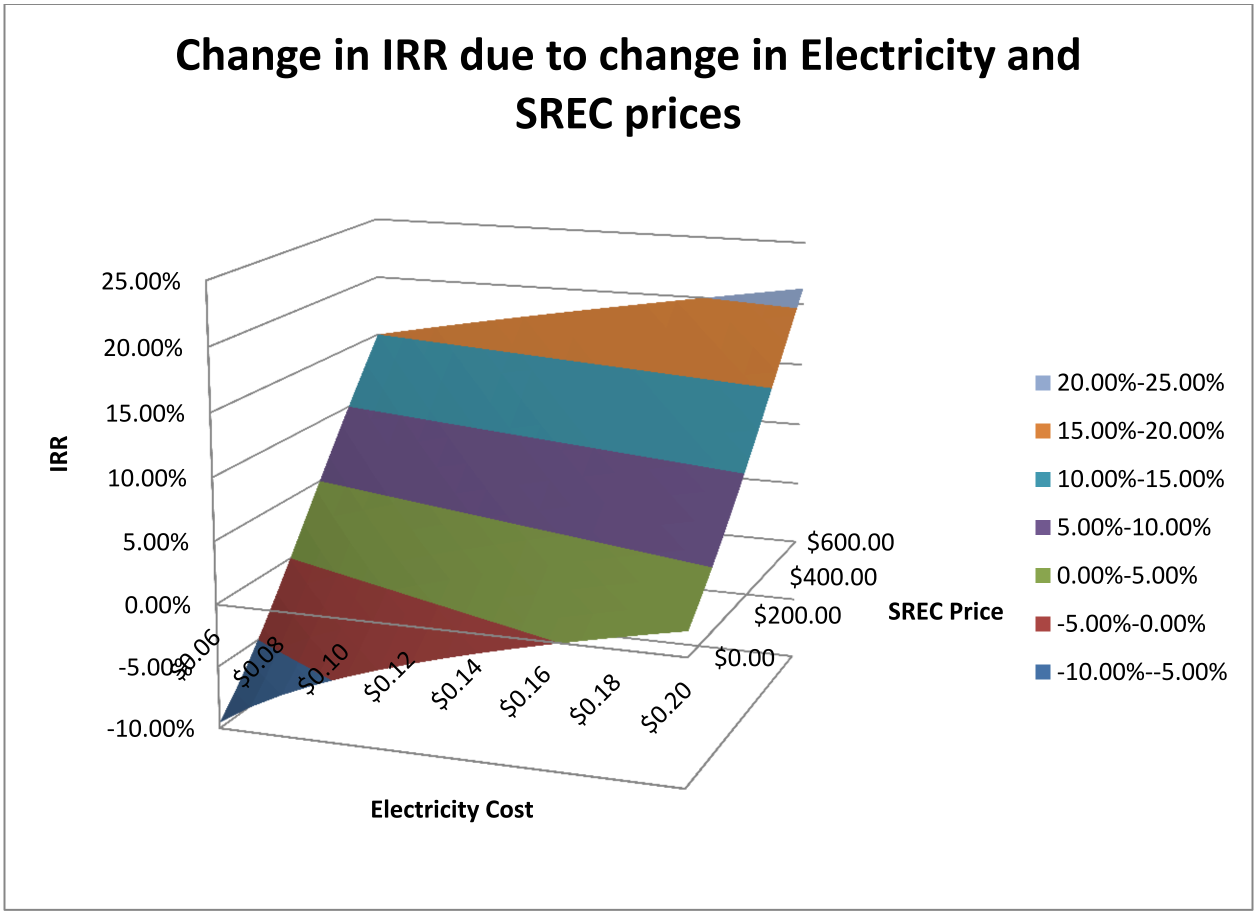


Figure 23: 3-dimensional IRR analysis

The sensitivity analysis of internal rate of return (IRR) shows similar results to thee analysis of profit. The predicted values of IRR range from 12-14% and reach 0% only when SREC prices drop well below the federal minimum of $285.

The various sensitivity analyses indicate that the average SREC price have the largest effect on array's profit. Despite varying SREC prices and the changing cost of electricity, a photovoltaic array on the roof of Gordon Library is a financially responsible decision.

Common beliefs about solar

After proving that solar is a financially viable option, there is one question that has yet to be answered: if photovoltaic systems are so viable, why doesn't everyone install one? Two main concerns with photovoltaics are the high upfront cost and long payoff period. The lack of photovoltaics in Massachusetts would suggest that installing an array is not a fiscally responsible decision. Success among other entities contradicts these common concerns; Butte College is one example of photovoltaic integration yielding positive results. [29]

Butte College and Photovoltaics

Butte College is located in Oroville, California. In 2004, the administration and staff set a goal to be grid positive by the year 2012. This means that they would generate more energy than the campus required. On July 26th, 2011, the college completed its goal, retrofitting the campus by undergoing three phases of solar installation projects.

Butte College achieved their goal by implementing a variety of programs to boost energy generation and reduce their energy consumption. Several changes include upgrading the HVAC systems and lighting retrofits. By doing this, Butte College reduced their overall electricity consumption by 33%. [29].

Figure 24: Interactive Kiosk on Butte's Campus [30]

Butte College installed their photovoltaic systems in three phases. The school has 25,000 solar panels located on their campus, offering students a hands-on learning experience through their solar training program. Phase 1 involved the construction of several arrays, totaling 1.06 MW of peak power generation. Phase 2 included an additional 858 kW of peak power generation. In total, the campus installed 5 arrays through the first two phases and was able to power 27 buildings, 4 greenhouses, and their water reclamation plant. There were over 10,000 panels on campus by the end of phase 2, as well as an interactive information kiosk for students on campus to learn about their arrays [31].

Phase 3 of the college’s solar initiative added 15,000 panels to their campus. This added 2.7 MW of power generation from 13 arrays installed on several buildings and parking lots. The Butte College Chico Center was the focal point of this phase, supporting an array with 450 kW of peak power generation. The total cost of phase 3 was $17 million; $12.65 million from low interest federal loans and $4.35 million invested by the college. Butte College will save an estimated $50-$75 million over the next 15 years, effectively “eliminating its electricity bill, getting paid for excess electricity production, and avoiding future electricity rate increases" [29]. A large portion of the savings will be reinvested into the curriculum and student programs, providing additional benefits for students on campus [32].

Figure 25: View of Campus [30]

In addition to the financial benefits for the college, the arrays will offset 6.9 million pounds of CO_2 annually. The arrays generate an estimated 6.5 MWh of electricity per year, the equivalent of powering 900 average-size homes. Butte College has been recognized by the Environmental Protection Agency (EPA) for its work with renewable energy generation and it the only school in the nation that is grid positive [32].

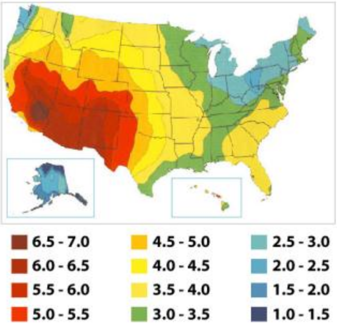


Figure 26: Solar efficiency based on geographical location [33]

It is important to note that there are several differences between California and Massachusetts when examining the use of photovoltaics. California receives more hours of direct sunlight per day than Massachusetts, as shown in figure 27. California is better suited for solar than Massachusetts in regards to the amount of energy produced per panel.

Another main factor regarding photovoltaics is the funding for an array. The 30% tax credit is a federal option, which applies to potential arrays in all states. This tax credit is capped at 1 MW, meaning that phase 2 and 3 of Butte College's solar energy were not eligible for this credit. Renewable Energy Credits are another way to boost the earnings of an array. Massachusetts's Solar Renewable Energy Credits (SREC's) can earn an extra $500 for each MWh of energy generated and increase WPI's profit over the lifetime of the photovoltaic system. In California, SREC credits do not exist due to the lack of a market. Tradable Renewable Energy Credits (TREC's) are the current equivalent in California. The price cap for TREC's is $50, or about 1/10th the value of these credits in

Massachusetts [34]. Because these credits are available for the first ten years of the array, this means that the earnings for an array in Worcester during this time would exceed the profit margin for a similar size array in California. California receives more hours of direct sunlight in relation to Massachusetts, meaning that they are able to generate more energy per square foot. While California generates more profit this way, SREC's allow photovoltaics to be a strong financial option in Massachusetts.

Conclusion

Worcester Polytechnic Institute is proud of its contributions to green energy and of being on the forefront of technological advancement. The addition of a photovoltaic array would only bolster this reputation. It has been shown that the Gordon Library rooftop is an ideal location for such an array; the building can withstand the added physical strain, and the resulting performance yields an impressive financial gain while offsetting a tremendous amount of carbon dioxide emissions.

Using calculations prepared in conjunction with WPI Facilities and Absolute Green Energy, a plan has been constructed with no upfront cost and a net gain of over $100,000. A payment plan will allow for this zero-capital loan to pay for itself in 6 years, never resulting in negative cash flow. The economic analysis proves that within reasonable circumstances, there is no negative outcome to installing a photovoltaic array on Gordon Library.

In addition to the economic outcome, the positive environmental impact will not be overlooked. Over a 25-year lifetime of the array, it has been predicted that over 1.3 million pounds of carbon dioxide emissions will be offset. For an institution already invested in providing green solutions, this is the next step in the right direction.

This array will boost WPI's public reputation in the Worcester community. It will advance WPI as an innovative technical institution on the forefront of renewable resource technology. It will prove our determination to be a community leader and show that we belong as a top educational university in the nation. This array will usher in an untapped resource exclusively available to WPI and its community members; the ability to interact directly with solar panels. This will present WPI with the unique opportunity to be on the forefront of educational research in the field of photovoltaic technology.

This array is an environmentally and financially responsible opportunity that will benefit all WPI community members, both present and future. This submitted plan has been achieved with collaboration of students, faculty and professionals. Responsibility now falls onto WPI’s Administration. The potential benefits of a photovoltaic array have been proven and are now in the administrators’ hands to bring these benefits to our community.

Appendix A. Useful Information

How Photovoltaic Panels Work

The term photovoltaic is used to describe the conversion of light energy into electricity at the atomic level. Photovoltaic panels work because some materials exhibit a property known as the photoelectric effect that causes them to absorb photons of light and release electrons [35]. These freed electrons are captured via wires surrounding the substrates on a solar panel, return to their substrate creates an electric current that can be used to power electrical devices.

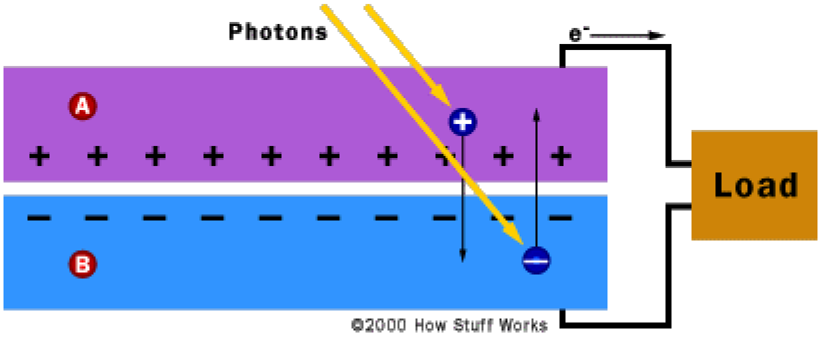


Figure 27: Showing the basic operation of a photovoltaic cell [36]

Figure 28 illustrates the basic operation of a photovoltaic cell. It shows how an electron is removed from the negative side of photovoltaic cell, and the electrical field between the two layers causes the electrons to travel to the negative side through the load. This allows us to generate electricity to power buildings or charge batteries.

The two halves to a solar cell consist primarily of silicon. Silicon is a great base due to its extremely stable nature. It will effectively bond with itself resulting in a weak conductor for electricity. For photovoltaic cells the silicon is doped (a process where impurities are introduced into an extremely pure substance) [37] with a substance that has a -3 charge (meaning it has three extra electrons) such has phosphorus. The resulting semiconductor has a net negative charge (meaning the pair has an extra electron) and is referred to as an N-type semiconductor. Silicon can also be doped with a positively charged element to create a net positive charge. This is classified as a P-type semiconductor.

The two semiconductors are layered on top of each other. Electrons flow from the N-type to the P-type semiconductor because of the imbalance in the electrons. When a photon strikes the photovoltaic cell electrons are forced across the electric field. These electrons are forced to travel back to the negative side through the connecting wires. By inducing an electrical load, we can convert the flow of electrons into electrical energy that can power applicable devices on WPI [38].

Past Reports

Photovoltaization of WPI

Photovoltaization of WPI [39] examined some of the reasons that solar is a viable option for WPI. The report examined some of the political and economic reasons behind the technology. In their own research, they reached the conclusion that the Bartlett center would be the ideal location for a photovoltaic array. They estimated their payoff period between 6 and 10 years depending on the available funding, grants, and tax incentives. A large section of the report discussed the history of solar and how it works. There were some rough estimates on how much such an installation would cost as well as two case studies. One was in regards to Boston Sand and Gravel and the new array installed at Worcester State College. The end of the report included some detailed economic analysis that looked at the future cost of electricity and the rate of return.

This report proved the validity of solar power, however it does not include a plan on how this can be integrated to WPI. The goal of this report is to prove that solar does work and provide an outline for WPI on how it can go about making this a reality [39].

Don’t Let the Sun Go Down on Boston without Harnessing its Energy Using Photovoltaic Technology IQP

In our search for information on emerging solar technology and implementation we found the 2008 WPI IQP Don’t Let the Sun Go Down on Boston without Harnessing its Energy Using Photovoltaic Technology [40]. This IQP focused on the benefits of installing photovoltaic panels and solar water heaters in the city of Boston to improve its green energy usage. The authors worked extensively with city of Boston and were able to gather important information in regards to the situation.

The group focused on the local company North Coast Seafood’s, which recently had a photovoltaic array installed on their main building. This array produces 119,000 kW per year of energy it cost around $1 to install. $500,000 of the upfront cost was covered by the

Massachusetts Technology Collaborative. The array covers between 9% and 10% of the companies energy demands, and the additional rebates (give example) North Coast Seafood's receives makes the array a good investment for the company.

Another factor covered by the report discusses the efficiency of other type of energy generation. The authors state that photovoltaic panels are 15% efficient in terms of converting solar radiation into electrical energy, whereas fossil fuels rein in at 30% for coal, 21% for natural gas and 9% for oil. Unfortunately burning oil is less efficient than using photovoltaic panels; this is a serious problem as the majority of the electricity produced in the United States is through the burning of oil. The authors pointed out that in the current economy people are not interested in the efficiencies of their electricity generators but rather on the costs.

The report also discusses the efficiency of other types of energy generation. The authors cite that the expected payoff period for photovoltaic panels is five to eight years. Considering that photovoltaic panels come with a 25 year warranty. This means that the array will create additional income for a household over its lifetime. The authors also cite that expected amount of rebates, to install photovoltaic panels, will decrease as more and more arrays are installed and more people claim money from the rebates.

Renewable Energy with Photovoltaic Systems

Renewable Energy with Photovoltaic Systems is an IQP report completed in 2007 by Nicholas Bebel, Garabed Hagopian, and Shane Larson [41]. Its purpose is to expose the problems related to fossil fuels, and describe the benefits of solar energy.

The report begins with outlining our nation's dependence on oil, explaining how we cannot rely on oil to power our future and we need preventative measures in place. The reasons we need to reduce our dependence on oil are the lack of remaining resources, the heavy expenses, and concerns for the environment. Alternative sources of energy must be in place before the oil supply runs out. Increasing fuel prices directly affect manufacturing, shipping companies, and the agriculture industry leading to higher prices for everyday products. When looking for alternative energy sources, another factor is the amount of CO2 emissions created. By working towards cleaner forms of energy we can offset the dwindling oil supplies and reduce the harmful CO2 byproduct that is harmful for the environment [2].

Appendix B. Company Information

Directory format:

Company name
Specialty
Commercial/residential
Address
Phone number
Website

Note that turnkey solar companies are companies that design, install, and maintain an array.

Advanced Energy Systems
Turnkey solar
Commercial and residential
474 Brookline Ave
Boston, MA 02215
(617)-598-2700
http://www.advancedenergysystemsusa.com

Alteris Renewables
Turnkey solar
Commercial and residential
56 Conduit Street
New Bedford, MA 02745
508-992-1416

Alternative Energy Store
PV distributor
Commercial and residential
65 Water Street
Worcester, MA 01604
(508)-421-8201
www.alternativeenergystore.com

Brightstar Solar
Turnkey solar
Commercial and residential
97 Strathmore Rd #8
Brighton, MA 02135
(617)-564-0050
http://www.brightstarsolar.net

Conservation Services Group
Specialty
Residential/commercial
40 Washington Street
Westborough, MA 01581
(508)-836-9500
www.csgrp.com

DC Solar
Turnkey solar
Commercial and residential
Address
(800)-327-6527
www.dcsolar.net

Evergreen Solar Inc.
Manufactures and distributes solar panels
Residential/commercial
138 Bartlett Street
Marlboro, MA 01752
(508)-357-2221
www.evergreensolar.com

GoGreenSolar
Online distributor
Commercial and residential
Address
(866)-798-4435
www.gogreensolar.com

Greenskies Renewable Energy
Solar installation
Commercial
10 Main St., Suite E
Middletown, CT 06457
(860)-398-5408
www.greenskies.com

Gro solar
Turnkey solar
Residential and commercial
17B Sterling Road
North Billerica, MA 01862
(800)-374-4494
www.grosolar.com

Johnson Controls
Performance contracts (guaranteed savings), turn key
Commercial
190 Carando Drive
Springfield, MA 01104
(413)-733-4060
www.johnsoncontrols.com

Kosmo Solar
Turnkey solar
Residential/commercial
PO Box 90597
Springfield, MA 01139
(413)-734-1456
www.kosmosolar.com

Munro Solar
Turnkey solar
Commercial
33 Commercial Street
Raynham, MA 02767
(800)-922-8385
www.munrosolar.com

New England Breeze LLC
Solar installation
Commercial and residential
16 Abigail Drive
Hudson, MA 01749
(978)-567-9463
www.newenglandbreeze.com

New England Solar Electric
Selling products
Residential
401 Huntington Road
PO Box 435
Worthington, MA 01098
(800)-914-4134
www.newenglandsolar.com

Nexamp
Analyze, design, install
Commercial
21 High Street Suite 209
North Andover, MA 01845
(978)-688-2700
http://www.nexamp.com/homeowner/turnkey_solutions/solar_pv

Northeast Sustainable Energy Association
Promoting sustainable energy solutions
Residential/commercial
50 Miles Street
Greenfield, MA 01301
(413)-774-6051
www.nesea.org

Pioneer Valley Photovoltaics Cooperative
Turnkey solar
Residential/Commercial
324 Wells Street
Greenfield, MA 01301
(413)-772-8788
www.pvsquared.coop

PowerBees
Turnkey
Residential/commercial
Solar heating, wind turbines
258 Pelham Island Road
Wayland, MA 01778
(617)-852-3888
www.powerbees.com

Renewable Energy Massachusetts LLC
Large scale PV displays
Commercial
17 Arlington Street
Cambridge, MA 02140
(617)-650-3557
www.remenergyco.com

Solar Wave Energy Inc.
Turnkey solar
Residential/commercial
523 Medford Street
Charlestown, MA 02129
(617)-242-2150
www.solarwave.com

Southcoast Greenlight
Turnkey solar
Commercial and residential
527 Wilbur Ave
Swansea, MA 02777
(508)-673-1100
www.southcoastgreenlight.com

Spire Solar
Turnkey solar
Commercial and residential
40 Wiggins Ave
Bedford, MA 01730
(781)-275-6000

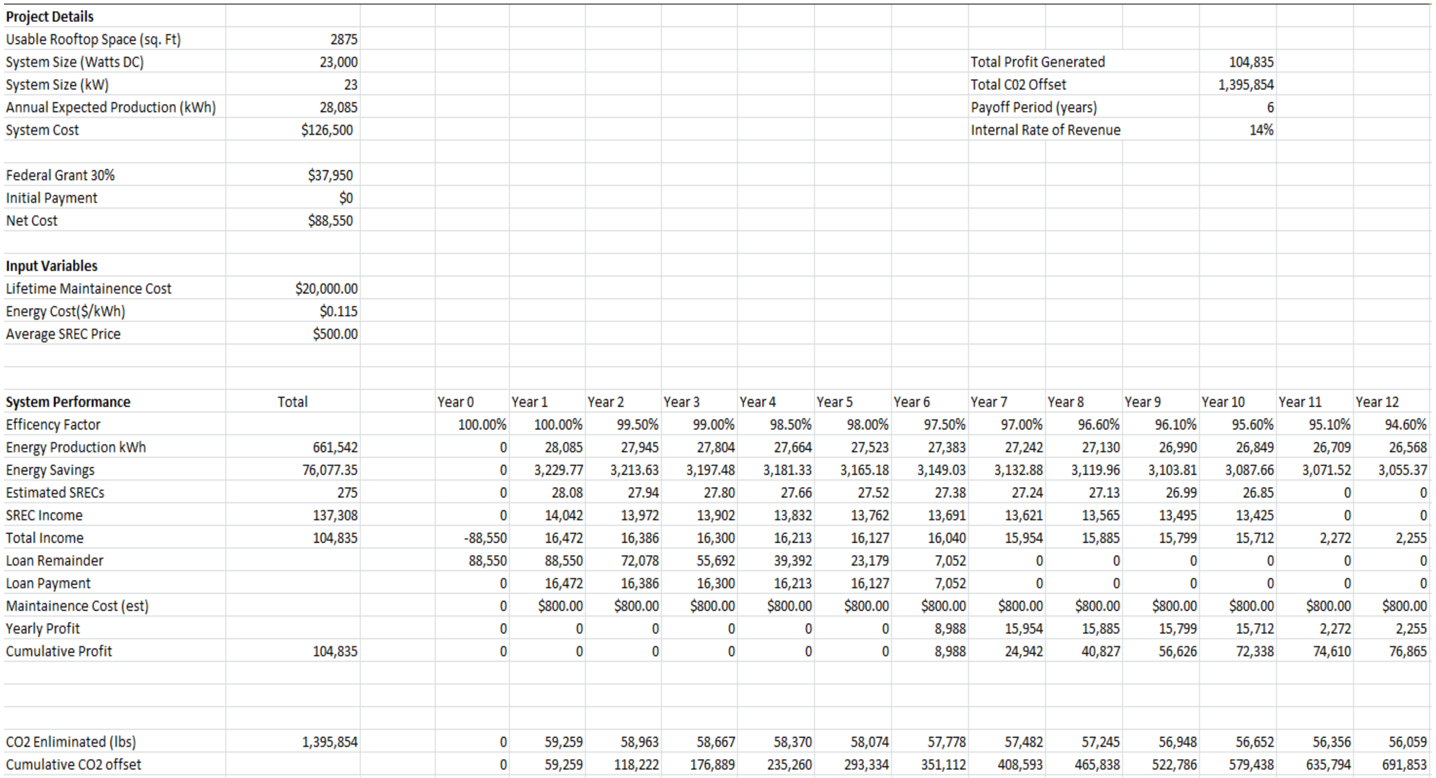
www.spirecorp.com

Sunbug Solar
Installation and design
Commercial
411A Highland Ave
Suite 312
Somerville, MA 02144
(866)-945-1727
www.sunbugsolar.com

Woodland Energy Store
Turnkey solar
Residential
200 Bush Hill Road
Ashburnham, MA 01420
(978)-827-3311
www.woodland-energy.com

Appendix C. Financial Spreadsheets

Gordon Library

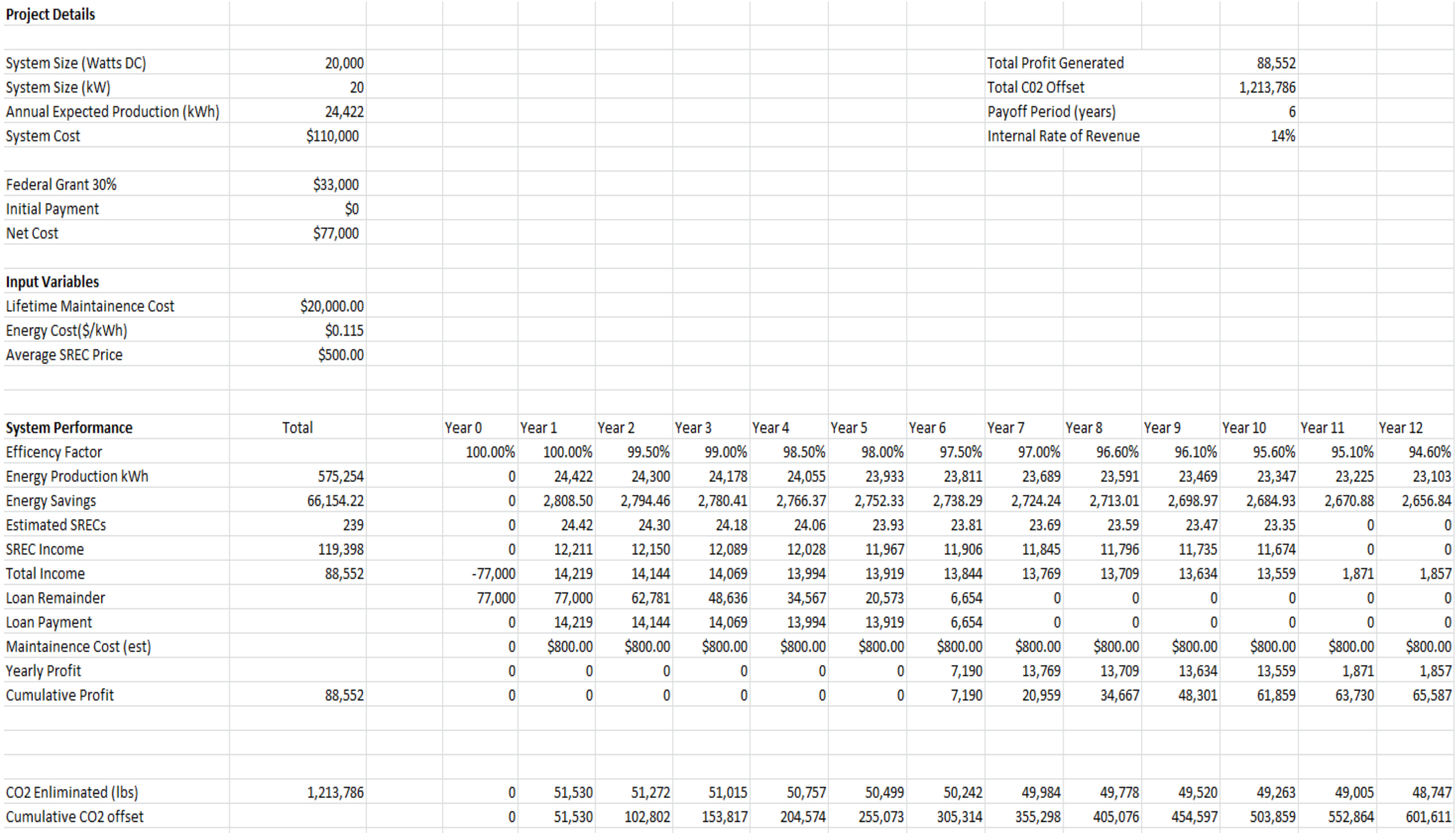


Project Details			
Usable Rooftop Space (sq. Ft)	2875		
System Size (Watts DC)	23,000	Total Profit Generated	104,835
System Size (kW)	23	Total C02 Offset	1,395,854
Annual Expected Production (kWh)	28,085	Payoff Period (years)	6
System Cost	$126,500	Internal Rate of Revenue	14%
Federal Grant 30%	$37,950		
Initial Payment	$0		
Net Cost	$88,550		
Input Variables			
Lifetime Maintainence Cost	$20,000.00		
Energy Cost($/kWh)	$0.115		
Average SREC Price	$500.00		

System Performance	Total	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12
Efficency Factor		100.00%	100.00%	99.50%	99.00%	98.50%	98.00%	97.50%	97.00%	96.60%	96.10%	95.60%	95.10%	94.60%
Energy Production kWh	661,542	0	28,085	27,945	27,804	27,664	27,523	27,383	27,242	27,130	26,990	26,849	26,709	26,568
Energy Savings	76,077.35	0	3,229.77	3,213.63	3,197.48	3,181.33	3,165.18	3,149.03	3,132.88	3,119.96	3,103.81	3,087.66	3,071.52	3,055.37
Estimated SRECs	275	0	28.08	27.94	27.80	27.66	27.52	27.38	27.24	27.13	26.99	26.85	0	0
SREC Income	137,308	0	14,042	13,972	13,902	13,832	13,762	13,691	13,621	13,565	13,495	13,425	0	0
Total Income	104,835	-88,550	16,472	16,386	16,300	16,213	16,127	16,040	15,954	15,885	15,799	15,712	2,272	2,255
Loan Remainder		88,550	88,550	72,078	55,692	39,392	23,179	7,052	0	0	0	0	0	0
Loan Payment		0	16,472	16,386	16,300	16,213	16,127	7,052	0	0	0	0	0	0
Maintainence Cost (est)		0	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00
Yearly Profit		0	0	0	0	0	0	8,988	15,954	15,885	15,799	15,712	2,272	2,255
Cumulative Profit	104,835	0	0	0	0	0	0	8,988	24,942	40,827	56,626	72,338	74,610	76,865
CO2 Enliminated (lbs)	1,395,854	0	59,259	58,963	58,667	58,370	58,074	57,778	57,482	57,245	56,948	56,652	56,356	56,059
Cumulative CO2 offset		0	59,259	118,222	176,889	235,260	293,334	351,112	408,593	465,838	522,786	579,438	635,794	691,853

Project Details														
Usable Rooftop Space (sq. Ft)	2875													
System Size (Watts DC)	23,000													
System Size (kW)	23													
Annual Expected Production (kWh)	28,085													
System Cost	$126,500													
Federal Grant 30%	$37,950													
Initial Payment	$0													
Net Cost	$88,550													
Input Variables														
Lifetime Maintainence Cost	$20,000.00													
Energy Cost($/kWh)	$0.115													
Average SREC Price	$500.00													
System Performance	Total	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23	Year 24	Year 25
Efficency Factor		94.20%	93.70%	93.20%	92.80%	92.30%	91.80%	91.40%	90.90%	90.40%	90.00%	89.50%	89.10%	88.70%
Energy Production kWh	661,542	26,456	26,316	26,175	26,063	25,922	25,782	25,670	25,529	25,389	25,276	25,136	25,024	24,911
Energy Savings	76,077.35	3,042.45	3,026.30	3,010.15	2,997.23	2,981.08	2,964.93	2,952.01	2,935.87	2,919.72	2,906.80	2,890.65	2,877.73	2,864.81
Estimated SRECs	275	0	0	0	0	0	0	0	0	0	0	0	0	0
SREC Income	137,308	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Income	104,835	2,242	2,226	2,210	2,197	2,181	2,165	2,152	2,136	2,120	2,107	2,091	2,078	2,065
Loan Remainder		0	0	0	0	0	0	0	0	0	0	0	0	0
Loan Payment		0	0	0	0	0	0	0	0	0	0	0	0	0
Maintainence Cost (est)		$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00
Yearly Profit		2,242	2,226	2,210	2,197	2,181	2,165	2,152	2,136	2,120	2,107	2,091	2,078	2,065
Cumulative Profit	104,835	79,108	81,334	83,544	85,741	87,922	90,087	92,239	94,375	96,495	98,602	100,692	102,770	104,835
CO2 Enliminated (lbs)	1,395,854	55,822	55,526	55,230	54,993	54,696	54,400	54,163	53,867	53,570	53,333	53,037	52,800	52,563
Cumulative CO2 offset		747,675	803,201	858,431	913,424	968,120	1,022,520	1,076,683	1,130,550	1,184,120	1,237,454	1,290,491	1,343,291	1,395,854

Campus Center



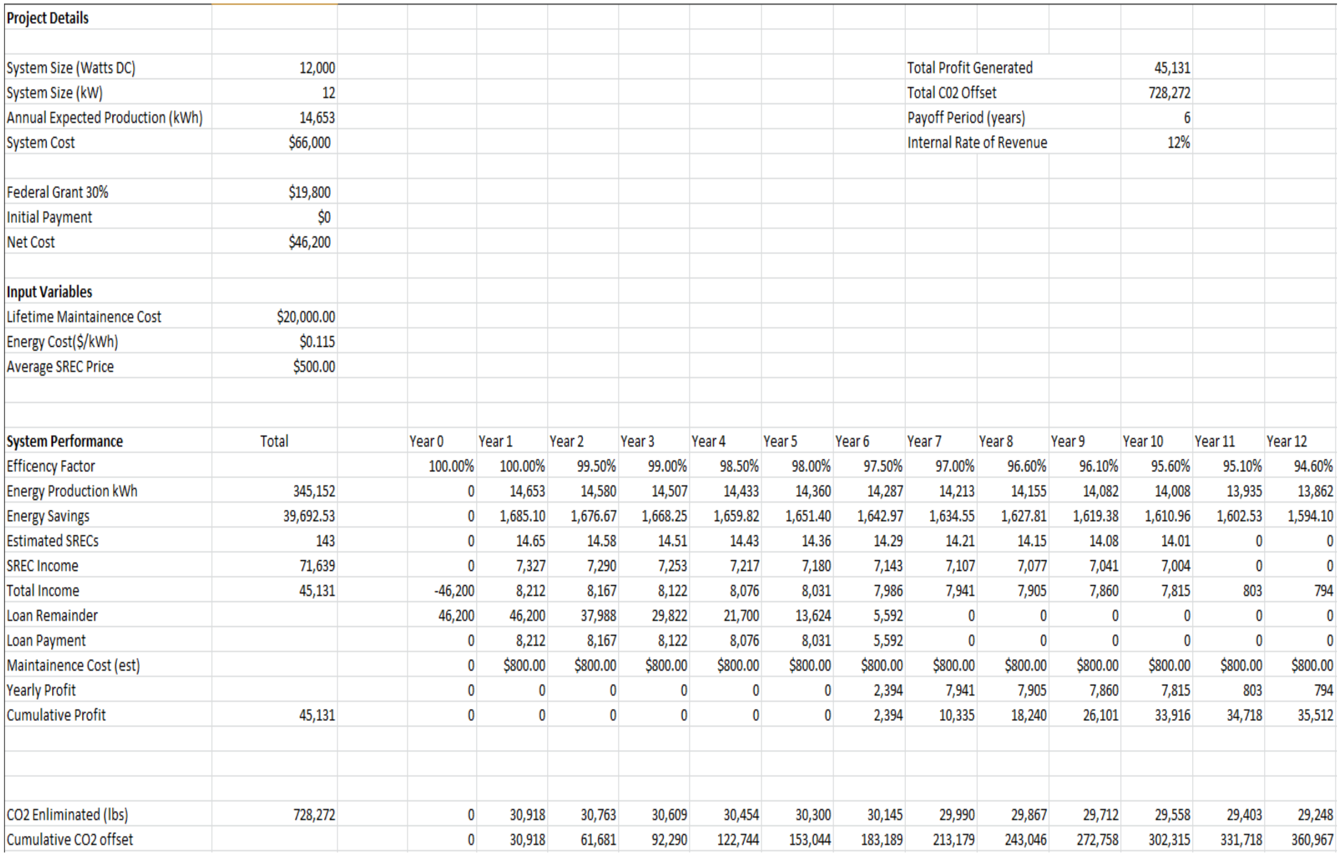
Project Details			
System Size (Watts DC)	20,000	Total Profit Generated	88,552
System Size (kW)	20	Total C02 Offset	1,213,786
Annual Expected Production (kWh)	24,422	Payoff Period (years)	6
System Cost	$110,000	Internal Rate of Revenue	14%
Federal Grant 30%	$33,000		
Initial Payment	$0		
Net Cost	$77,000		
Input Variables			
Lifetime Maintainence Cost	$20,000.00		
Energy Cost($/kWh)	$0.115		
Average SREC Price	$500.00		

System Performance	Total	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12
Efficency Factor		100.00%	100.00%	99.50%	99.00%	98.50%	98.00%	97.50%	97.00%	96.60%	96.10%	95.60%	95.10%	94.60%
Energy Production kWh	575,254	0	24,422	24,300	24,178	24,055	23,933	23,811	23,689	23,591	23,469	23,347	23,225	23,103
Energy Savings	66,154.22	0	2,808.50	2,794.46	2,780.41	2,766.37	2,752.33	2,738.29	2,724.24	2,713.01	2,698.97	2,684.93	2,670.88	2,656.84
Estimated SRECs	239	0	24.42	24.30	24.18	24.06	23.93	23.81	23.69	23.59	23.47	23.35	0	0
SREC Income	119,398	0	12,211	12,150	12,089	12,028	11,967	11,906	11,845	11,796	11,735	11,674	0	0
Total Income	88,552	-77,000	14,219	14,144	14,069	13,994	13,919	13,844	13,769	13,709	13,634	13,559	1,871	1,857
Loan Remainder		77,000	77,000	62,781	48,636	34,567	20,573	6,654	0	0	0	0	0	0
Loan Payment		0	14,219	14,144	14,069	13,994	13,919	6,654	0	0	0	0	0	0
Maintainence Cost (est)		0	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00
Yearly Profit		0	0	0	0	0	0	7,190	13,769	13,709	13,634	13,559	1,871	1,857
Cumulative Profit	88,552	0	0	0	0	0	0	7,190	20,959	34,667	48,301	61,859	63,730	65,587
CO2 Enliminated (lbs)	1,213,786	0	51,530	51,272	51,015	50,757	50,499	50,242	49,984	49,778	49,520	49,263	49,005	48,747
Cumulative CO2 offset		0	51,530	102,802	153,817	204,574	255,073	305,314	355,298	405,076	454,597	503,859	552,864	601,611

Project Details	
System Size (Watts DC)	20,000
System Size (kW)	20
Annual Expected Production (kWh)	24,422
System Cost	$110,000
Federal Grant 30%	$33,000
Initial Payment	$0
Net Cost	$77,000
Input Variables	
Lifetime Maintainence Cost	$20,000.00
Energy Cost($/kWh)	$0.115
Average SREC Price	$500.00

System Performance	Total	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23	Year 24	Year 25
Efficency Factor		94.20%	93.70%	93.20%	92.80%	92.30%	91.80%	91.40%	90.90%	90.40%	90.00%	89.50%	89.10%	88.70%
Energy Production kWh	575,254	23,005	22,883	22,761	22,663	22,541	22,419	22,321	22,199	22,077	21,980	21,857	21,760	21,662
Energy Savings	66,154.22	2,645.61	2,631.56	2,617.52	2,606.29	2,592.25	2,578.20	2,566.97	2,552.93	2,538.88	2,527.65	2,513.61	2,502.37	2,491.14
Estimated SRECs	239	0	0	0	0	0	0	0	0	0	0	0	0	0
SREC Income	119,398	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Income	88,552	1,846	1,832	1,818	1,806	1,792	1,778	1,767	1,753	1,739	1,728	1,714	1,702	1,691
Loan Remainder		0	0	0	0	0	0	0	0	0	0	0	0	0
Loan Payment		0	0	0	0	0	0	0	0	0	0	0	0	0
Maintainence Cost (est)		$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00
Yearly Profit		1,846	1,832	1,818	1,806	1,792	1,778	1,767	1,753	1,739	1,728	1,714	1,702	1,691
Cumulative Profit	88,552	67,433	69,264	71,082	72,888	74,680	76,459	78,226	79,978	81,717	83,445	85,159	86,861	88,552
CO2 Enliminated (lbs)	1,213,786	48,541	48,283	48,026	47,820	47,562	47,304	47,098	46,841	46,583	46,377	46,119	45,913	45,707
Cumulative CO2 offset		650,152	698,436	746,462	794,281	841,843	889,148	936,246	983,087	1,029,670	1,076,047	1,122,166	1,168,079	1,213,786

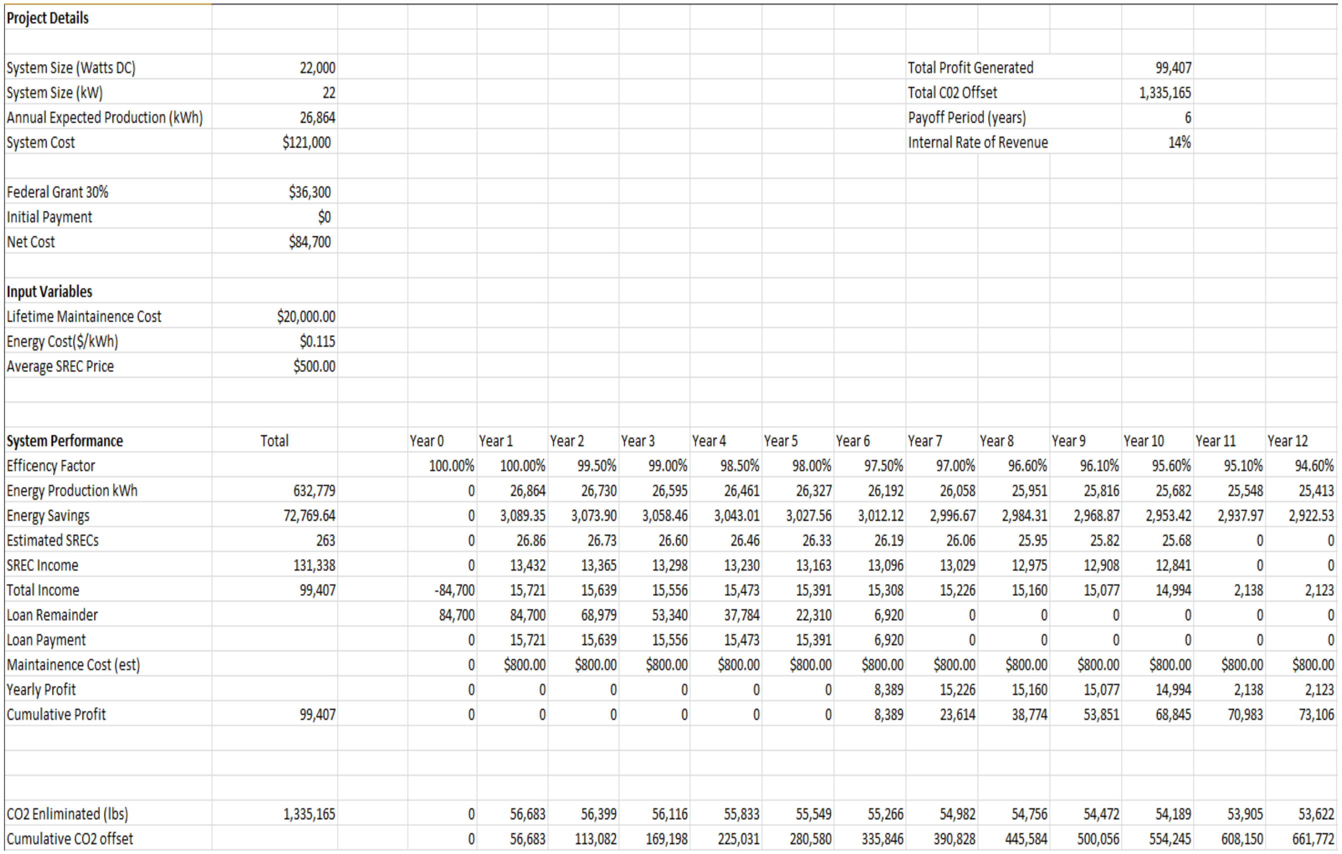
Bartlett Center



Project Details															
System Size (Watts DC)	12,000									Total Profit Generated			45,131		
System Size (kW)	12									Total C02 Offset			728,272		
Annual Expected Production (kWh)	14,653									Payoff Period (years)			6		
System Cost	$66,000									Internal Rate of Revenue			12%		
Federal Grant 30%	$19,800														
Initial Payment	$0														
Net Cost	$46,200														
Input Variables															
Lifetime Maintainence Cost	$20,000.00														
Energy Cost($/kWh)	$0.115														
Average SREC Price	$500.00														
System Performance	Total		Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12
Efficency Factor			100.00%	100.00%	99.50%	99.00%	98.50%	98.00%	97.50%	97.00%	96.60%	96.10%	95.60%	95.10%	94.60%
Energy Production kWh	345,152		0	14,653	14,580	14,507	14,433	14,360	14,287	14,213	14,155	14,082	14,008	13,935	13,862
Energy Savings	39,692.53		0	1,685.10	1,676.67	1,668.25	1,659.82	1,651.40	1,642.97	1,634.55	1,627.81	1,619.38	1,610.96	1,602.53	1,594.10
Estimated SRECs	143		0	14.65	14.58	14.51	14.43	14.36	14.29	14.21	14.15	14.08	14.01	0	0
SREC Income	71,639		0	7,327	7,290	7,253	7,217	7,180	7,143	7,107	7,077	7,041	7,004	0	0
Total Income	45,131		-46,200	8,212	8,167	8,122	8,076	8,031	7,986	7,941	7,905	7,860	7,815	803	794
Loan Remainder			46,200	46,200	37,988	29,822	21,700	13,624	5,592	0	0	0	0	0	0
Loan Payment			0	8,212	8,167	8,122	8,076	8,031	5,592	0	0	0	0	0	0
Maintainence Cost (est)			0	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00
Yearly Profit			0	0	0	0	0	0	2,394	7,941	7,905	7,860	7,815	803	794
Cumulative Profit	45,131		0	0	0	0	0	0	2,394	10,335	18,240	26,101	33,916	34,718	35,512
CO2 Enliminated (lbs)	728,272		0	30,918	30,763	30,609	30,454	30,300	30,145	29,990	29,867	29,712	29,558	29,403	29,248
Cumulative CO2 offset			0	30,918	61,681	92,290	122,744	153,044	183,189	213,179	243,046	272,758	302,315	331,718	360,967

Project Details														
System Size (Watts DC)	12,000													
System Size (kW)	12													
Annual Expected Production (kWh)	14,653													
System Cost	$66,000													
Federal Grant 30%	$19,800													
Initial Payment	$0													
Net Cost	$46,200													
Input Variables														
Lifetime Maintainence Cost	$20,000.00													
Energy Cost($/kWh)	$0.115													
Average SREC Price	$500.00													
System Performance	Total	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23	Year 24	Year 25
Efficency Factor		94.20%	93.70%	93.20%	92.80%	92.30%	91.80%	91.40%	90.90%	90.40%	90.00%	89.50%	89.10%	88.70%
Energy Production kWh	345,152	13,803	13,730	13,657	13,598	13,525	13,451	13,393	13,320	13,246	13,188	13,114	13,056	12,997
Energy Savings	39,692.53	1,587.36	1,578.94	1,570.51	1,563.77	1,555.35	1,546.92	1,540.18	1,531.76	1,523.33	1,516.59	1,508.16	1,501.42	1,494.68
Estimated SRECs	143	0	0	0	0	0	0	0	0	0	0	0	0	0
SREC Income	71,639	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Income	45,131	787	779	771	764	755	747	740	732	723	717	708	701	695
Loan Remainder		0	0	0	0	0	0	0	0	0	0	0	0	0
Loan Payment		0	0	0	0	0	0	0	0	0	0	0	0	0
Maintainence Cost (est)		$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00
Yearly Profit		787	779	771	764	755	747	740	732	723	717	708	701	695
Cumulative Profit	45,131	36,300	37,079	37,849	38,613	39,368	40,115	40,855	41,587	42,310	43,027	43,735	44,437	45,131
CO2 Enliminated (lbs)	728,272	29,125	28,970	28,816	28,692	28,537	28,383	28,259	28,104	27,950	27,826	27,672	27,548	27,424
Cumulative CO2 offset		390,091	419,062	447,877	476,569	505,106	533,489	561,748	589,852	617,802	645,628	673,300	700,847	728,272

Daniels Hall



Project Details	
System Size (Watts DC)	22,000
System Size (kW)	22
Annual Expected Production (kWh)	26,864
System Cost	$121,000
Federal Grant 30%	$36,300
Initial Payment	$0
Net Cost	$84,700
Input Variables	
Lifetime Maintainence Cost	$20,000.00
Energy Cost($/kWh)	$0.115
Average SREC Price	$500.00

Total Profit Generated	99,407
Total C02 Offset	1,335,165
Payoff Period (years)	6
Internal Rate of Revenue	14%

System Performance	Total		Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12
Efficency Factor			100.00%	100.00%	99.50%	99.00%	98.50%	98.00%	97.50%	97.00%	96.60%	96.10%	95.60%	95.10%	94.60%
Energy Production kWh	632,779		0	26,864	26,730	26,595	26,461	26,327	26,192	26,058	25,951	25,816	25,682	25,548	25,413
Energy Savings	72,769.64		0	3,089.35	3,073.90	3,058.46	3,043.01	3,027.56	3,012.12	2,996.67	2,984.31	2,968.87	2,953.42	2,937.97	2,922.53
Estimated SRECs	263		0	26.86	26.73	26.60	26.46	26.33	26.19	26.06	25.95	25.82	25.68	0	0
SREC Income	131,338		0	13,432	13,365	13,298	13,230	13,163	13,096	13,029	12,975	12,908	12,841	0	0
Total Income	99,407		-84,700	15,721	15,639	15,556	15,473	15,391	15,308	15,226	15,160	15,077	14,994	2,138	2,123
Loan Remainder			84,700	84,700	68,979	53,340	37,784	22,310	6,920	0	0	0	0	0	0
Loan Payment			0	15,721	15,639	15,556	15,473	15,391	6,920	0	0	0	0	0	0
Maintainence Cost (est)			0	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00
Yearly Profit			0	0	0	0	0	0	8,389	15,226	15,160	15,077	14,994	2,138	2,123
Cumulative Profit	99,407		0	0	0	0	0	0	8,389	23,614	38,774	53,851	68,845	70,983	73,106
CO2 Enliminated (lbs)	1,335,165		0	56,683	56,399	56,116	55,833	55,549	55,266	54,982	54,756	54,472	54,189	53,905	53,622
Cumulative CO2 offset			0	56,683	113,082	169,198	225,031	280,580	335,846	390,828	445,584	500,056	554,245	608,150	661,772

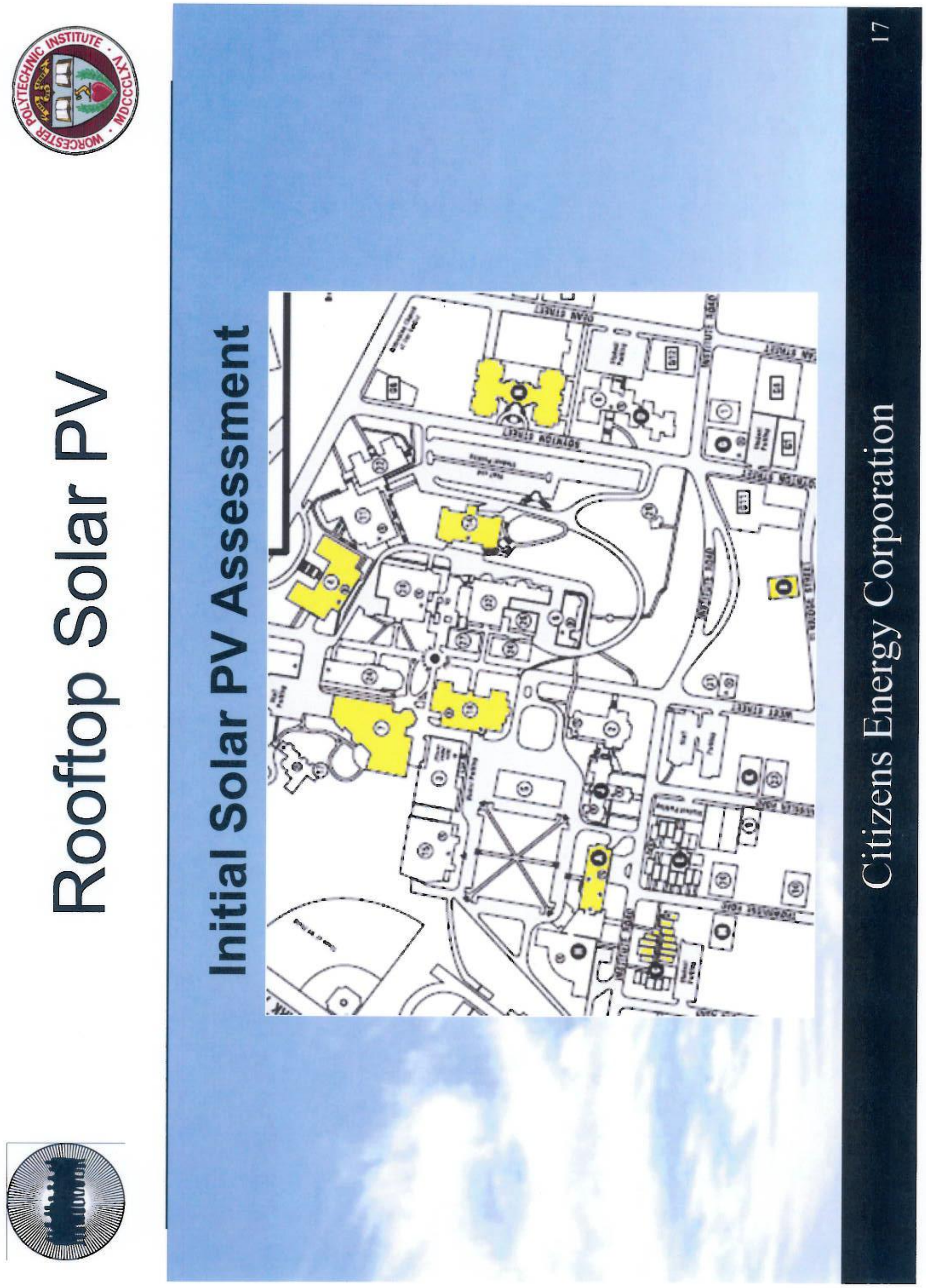
Project Details	
System Size (Watts DC)	22,000
System Size (kW)	22
Annual Expected Production (kWh)	26,864
System Cost	$121,000
Federal Grant 30%	$36,300
Initial Payment	$0
Net Cost	$84,700
Input Variables	
Lifetime Maintainence Cost	$20,000.00
Energy Cost($/kWh)	$0.115
Average SREC Price	$500.00

System Performance	Total	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23	Year 24	Year 25
Efficency Factor		94.20%	93.70%	93.20%	92.80%	92.30%	91.80%	91.40%	90.90%	90.40%	90.00%	89.50%	89.10%	88.70%
Energy Production kWh	632,779	25,306	25,171	25,037	24,930	24,795	24,661	24,554	24,419	24,285	24,178	24,043	23,936	23,828
Energy Savings	72,769.64	2,910.17	2,894.72	2,879.27	2,866.92	2,851.47	2,836.02	2,823.67	2,808.22	2,792.77	2,780.41	2,764.97	2,752.61	2,740.25
Estimated SRECs	263	0	0	0	0	0	0	0	0	0	0	0	0	0
SREC Income	131,338	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Income	99,407	2,110	2,095	2,079	2,067	2,051	2,036	2,024	2,008	1,993	1,980	1,965	1,953	1,940
Loan Remainder		0	0	0	0	0	0	0	0	0	0	0	0	0
Loan Payment		0	0	0	0	0	0	0	0	0	0	0	0	0
Maintainence Cost (est)		$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00
Yearly Profit		2,110	2,095	2,079	2,067	2,051	2,036	2,024	2,008	1,993	1,980	1,965	1,953	1,940
Cumulative Profit	99,407	75,216	77,311	79,390	81,457	83,508	85,544	87,568	89,576	91,569	93,549	95,514	97,467	99,407
CO2 Enliminated (lbs)	1,335,165	53,395	53,112	52,828	52,602	52,318	52,035	51,808	51,525	51,241	51,015	50,731	50,504	50,278
Cumulative CO2 offset		715,168	768,279	821,108	873,710	926,028	978,063	1,029,871	1,081,396	1,132,637	1,183,651	1,234,383	1,284,887	1,335,165

Method Example

Inputs		
Area	3000	ft^2
Cost of electricty/kWh	0.11	$
SREC value	500	$ per SREC
Calculated		
Size of array	24	kW
Upfront cost of array	132,000	$
Upfront cost after tax credit	92,400	$
Ideal power generation	29,304	kW/year
Energy generated years 0-9	285,714	kWh
Energy generated years 10-19	271,062	kWh
Energy generated years 20-25	156,044	kWh
Total energy generated	712,820	kWh
SRECs generated over 10 years	286	SRECs
Money earned from SRECS over 10 years	142,857.00	$
Money earned from power generated year 0-9	31,428.54	$
Money earned from power generation year 10-25	46,981.64	$
Earnings from year 0-9	174,285.54	$
Earnings over lifetime	221,267.18	$
Total profit	128,867.18	$

Appendix D: Citizen's Energy Report



Rooftop Solar PV

Initial Solar PV Assessment

Citizens Energy Corporation

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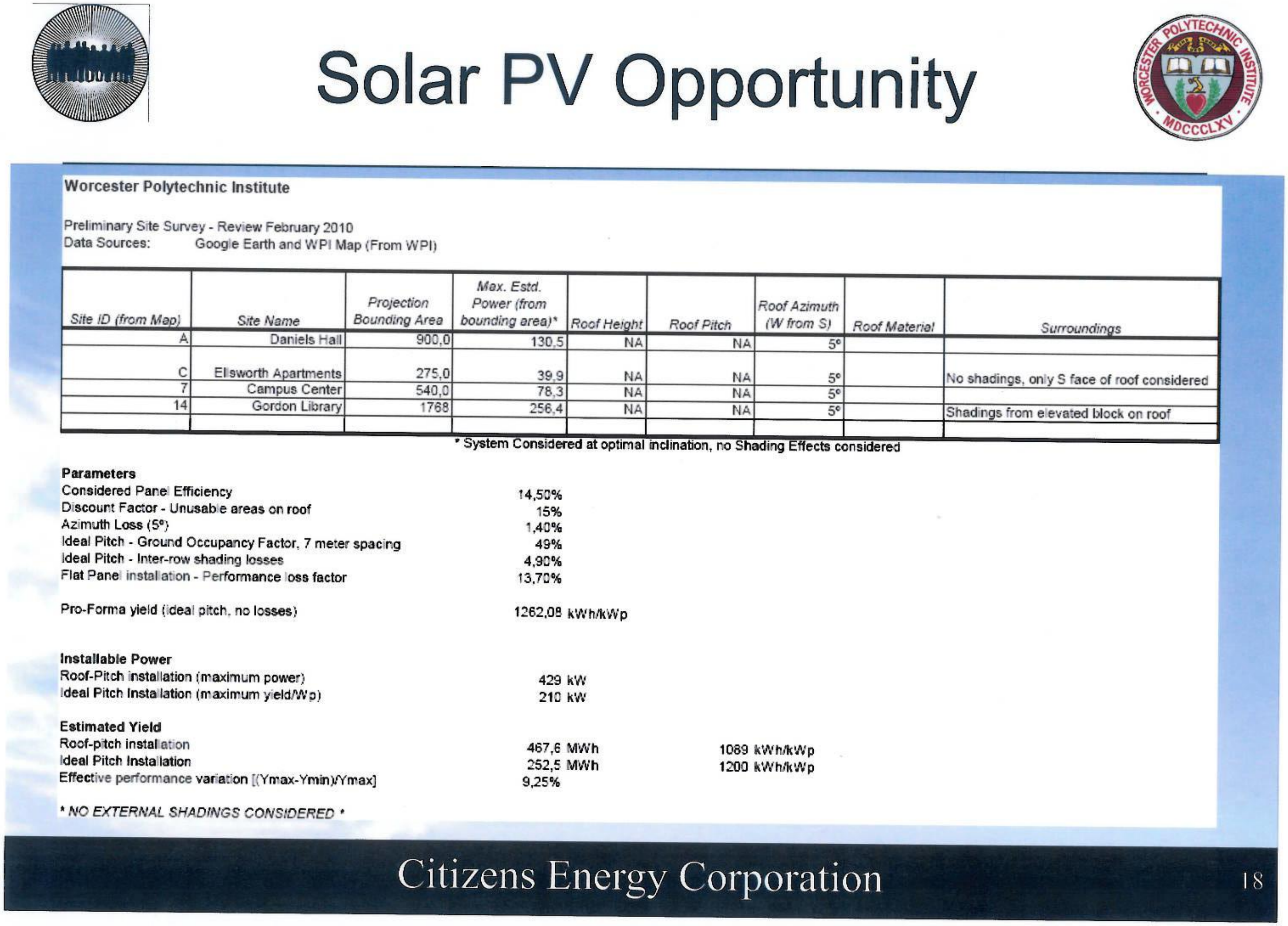


Solar PV Opportunity

Worcester Polytechnic Institute

Preliminary Site Survey - Review February 2010
Data Sources: Google Earth and WPI Map (From WPI)

Site ID (from Map)	*Site Name*	*Projection Bounding Area*	*Max. Estd. Power (from bounding area)**	*Roof Height*	*Roof Pitch*	*Roof Azimuth (W from S)*	*Roof Material*	*Surroundings*
A	Daniels Hall	900,0	130,5	NA	NA	5°		
C	Ellsworth Apartments	275,0	39,9	NA	NA	5°		No shadings, only S face of roof considered
7	Campus Center	540,0	78,3	NA	NA	5°		
14	Gordon Library	1768	256,4	NA	NA	5°		Shadings from elevated block on roof

* System Considered at optimal inclination, no Shading Effects considered

Parameters

Considered Panel Efficiency	14,50%
Discount Factor - Unusable areas on roof	15%
Azimuth Loss (5°)	1,40%
Ideal Pitch - Ground Occupancy Factor, 7 meter spacing	49%
Ideal Pitch - Inter-row shading losses	4,90%
Flat Panel installation - Performance loss factor	13,70%
Pro-Forma yield (ideal pitch, no losses)	1262,08 kWh/kWp

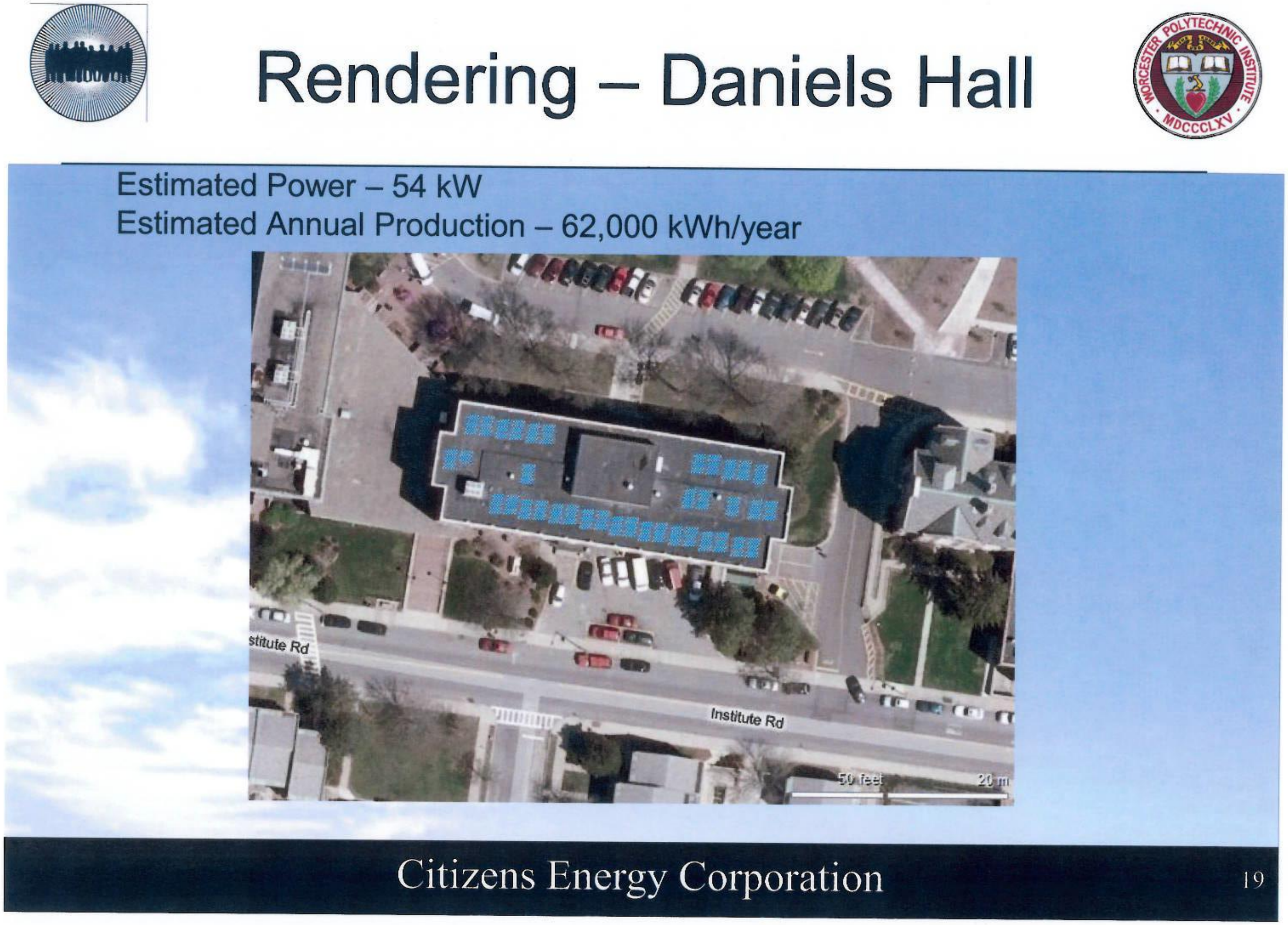
Installable Power

Roof-Pitch installation (maximum power)	429 kW
Ideal Pitch Installation (maximum yield/Wp)	210 kW

Estimated Yield

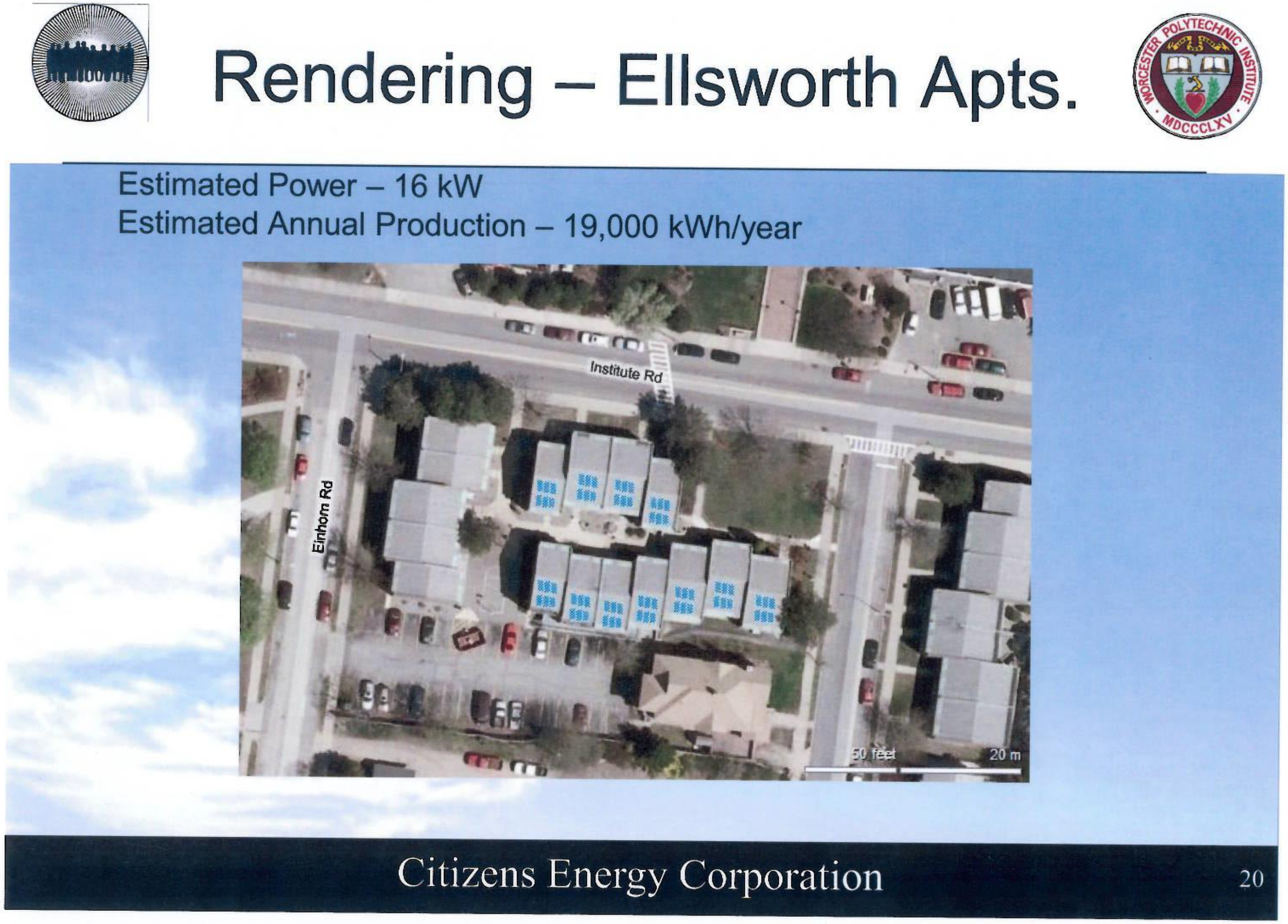
Roof-pitch installation	467,6 MWh	1089 kWh/kWp
Ideal Pitch Installation	252,5 MWh	1200 kWh/kWp
Effective performance variation [(Ymax-Ymin)/Ymax]	9,25%	

* *NO EXTERNAL SHADINGS CONSIDERED* *



Rendering – Daniels Hall

Estimated Power – 54 kW
Estimated Annual Production – 62,000 kWh/year



Rendering – Ellsworth Apts.

Estimated Power – 16 kW
Estimated Annual Production – 19,000 kWh/year

Citizens Energy Corporation

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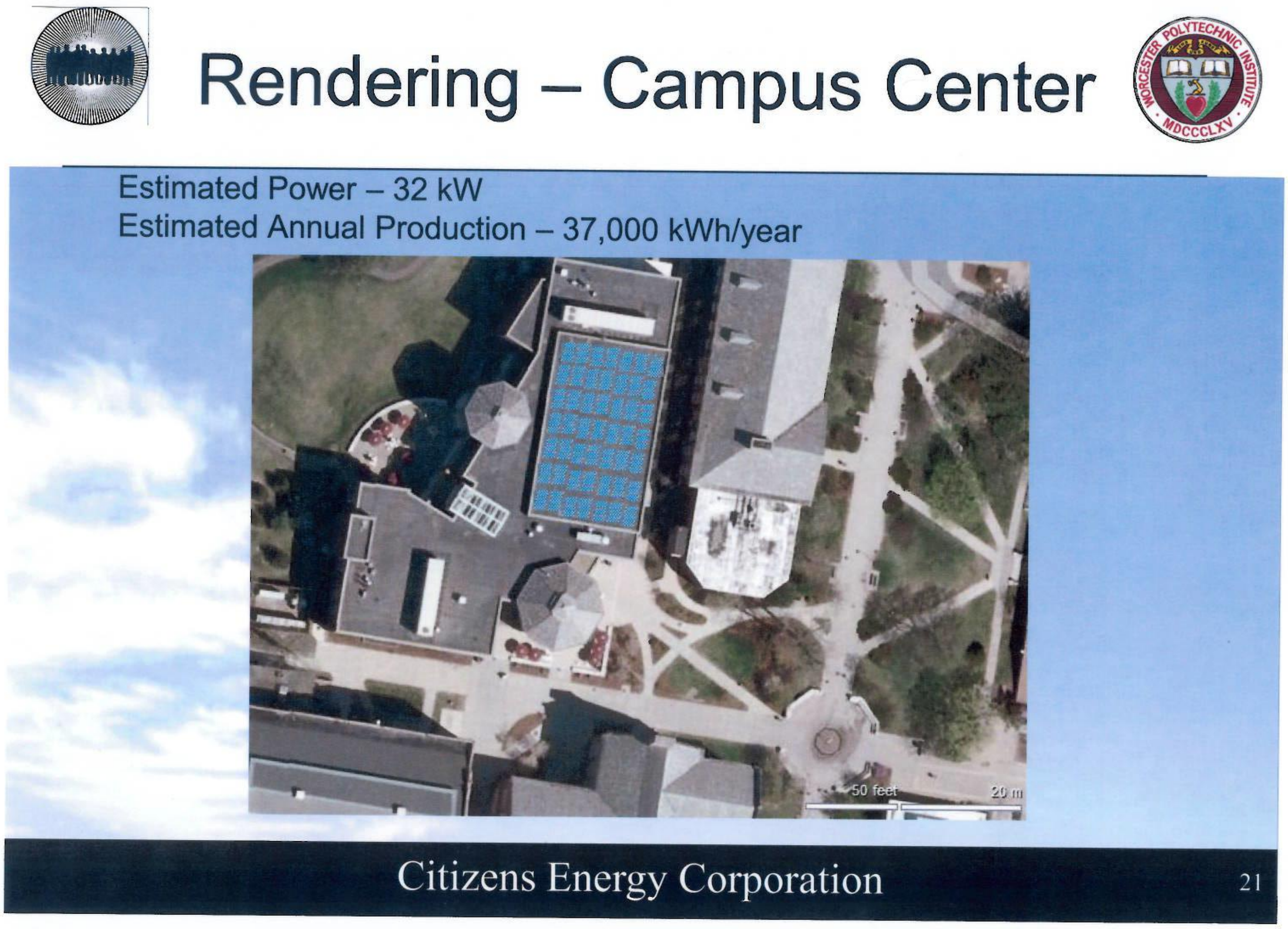


Rendering – Campus Center

Estimated Power – 32 kW
Estimated Annual Production – 37,000 kWh/year

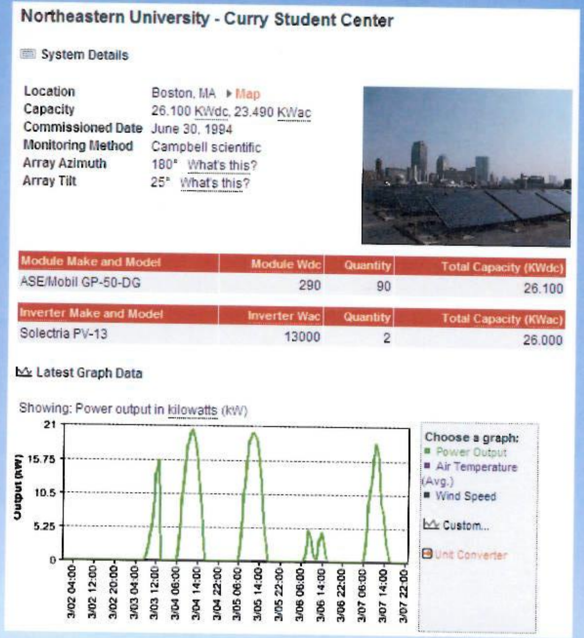
Rendering – Gordon Library

Estimated Power – 106 kW
Estimated Annual Production – 122,000 kWh/year

Renewable Energy

Real Time Reporting

- **Solar PV**
- Data Rich Output
- Generation kWh
- Historical data
- Carbon reductions



Northeastern University - Curry Student Center

System Details

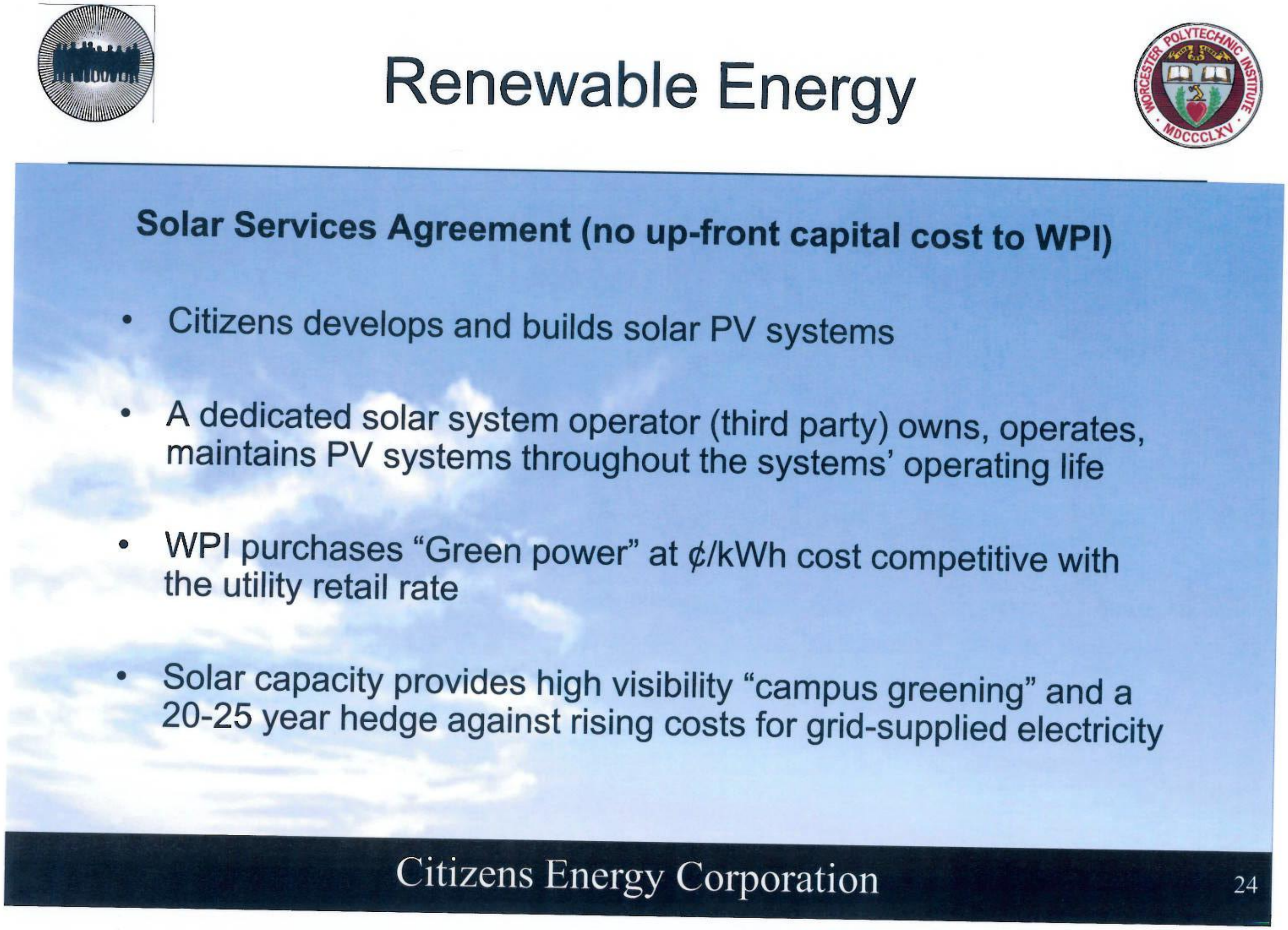
Location	Boston, MA ▸ Map
Capacity	26.100 KWdc, 23.490 KWac
Commissioned Date	June 30, 1994
Monitoring Method	Campbell scientific
Array Azimuth	180° What's this?
Array Tilt	25° What's this?

Module Make and Model	Module Wdc	Quantity	Total Capacity (KWdc)
ASE/Mobil GP-50-DG	290	90	26.100

Inverter Make and Model	Inverter Wac	Quantity	Total Capacity (KWac)
Solectria PV-13	13000	2	26.000

Latest Graph Data

Showing: Power output in kilowatts (kW)



Renewable Energy

Solar Services Agreement (no up-front capital cost to WPI)

- Citizens develops and builds solar PV systems
- A dedicated solar system operator (third party) owns, operates, maintains PV systems throughout the systems' operating life
- WPI purchases "Green power" at ¢/kWh cost competitive with the utility retail rate
- Solar capacity provides high visibility "campus greening" and a 20-25 year hedge against rising costs for grid-supplied electricity

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