ENVISIONING SOLAR PANEL CANOPY SYSTEMS AT WPI

An Interactive Qualifying Project Submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
In partial fulfillment of the requirements for the Degree of Bachelor of Science
by

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Sustaining WPI Project Center 2019

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Abstract

This project assessed the feasibility of WPI's parking areas for a solar canopy system, and developed a recommendation for the most effective option. Potential locations around campus were analyzed, with total area, sunlight exposure, and local topography taken into account. Regional climate patterns and solar incentives were also considered. Best practices were learned through interviews with solar installation companies and other schools with solar canopies. Ultimately, a comprehensive cost/benefit analysis was completed to estimate installation costs and payback periods.

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Authorship

Jacob Bernier is responsible for researching and writing about solar incentives and funding options, canopy support types, and much of the general organization of the report. He conducted background research on case studies and energy statistics, and was the primary author of the introduction, abstract, and executive summary sections. He also created AutoCAD files and design matrices, and calculated lot area using GIS and tape measurements. In addition, he contributed to the location analysis, and was the primary creator of the payback analysis data sheets. He was also responsible for presenting our findings at the Sustainability Plan Community Update.

Gabrielle Brown is responsible for researching background information regarding solar panel considerations as well as organizing the interviews. She reached out to stakeholders and created interview questions. She then summarized the information obtained and used it to support the lot and canopy designs selected as the most feasible. She planned deliverables and outlined the components needed for a formal proposal. She discussed and analyzed non-monetary benefits associated with solar panel canopies. She was responsible for the conclusion chapter.

Michael Hartwick is responsible for compiling a majority of the information regarding the specifics on renewable solar energy, such as its importance in implementation and the statistics on solar panels themselves. He developed the process in which the cost vs. benefit analysis was carried out including the cost of the system, the energy it would provide, and specific payback periods based on location and canopy type. He also compiled the solar pathfinder analysis data and led discussions when conducting interviews.

This report and project was a team effort with all members contributing equally.
The following section displays the primary author or authors for each subsection of the report.

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Executive Summary

Over recent decades, the inevitability of climate change and the need to develop more sustainable energy use practices has become clear. Hydro, wind, and solar power produce significantly less greenhouse gas emissions and are a more sustainable energy source than finite coal and natural gas reserves. The state of Massachusetts has become a leader in the development of solar energy during this time by setting aggressive target goals and creating numerous incentive programs. Solar panels can be seen across residential homes, corporate offices, and even college campuses such as Stonehill, Endicott, Harvard, and many more. Despite this, Worcester Polytechnic Institute (WPI) has not taken advantage of these programs that bolster the existing social and economic benefits of utilizing renewable energy.

Our project focused on solar canopies, which are structures that support solar panels over a parking area. This was chosen over the more commonplace rooftop panels as a previous IQP had already examined these. WPI's parking areas also provide a larger footprint and opportunity for more energy generation than its rooftops. In addition, the use of a canopy system provides numerous additional benefits such as a more efficient use of space, shelter for vehicles, and potential adaptation to support electric vehicle (EV) charging stations.

Initially, we determined what renewable forms of energy are already used by WPI, and whether these were generated on site or purchased from off site. This information helped us to establish the need for more sustainable energy. We also identified the key faculty and staff members involved in WPI's sustainability structure to provide us a list of suitable contacts.

We next read a number of case studies to better understand the typical process of a solar feasibility study, and the process of installing a solar canopy system. We focused on the development of a solar panel canopy at Stonehill College and a feasibility study for PV rooftop solar panels in Fairbanks, Alaska. We also researched federal and state level incentives for solar energy, and research possible funding options. These include programs such as Federal income tax credit (ITC), Solar Massachusetts Renewable Energy Target (SMART), and Modified Accelerated Cost Recovery System (MACRS).

Following this, we went out to conduct or location analysis of WPI's various parking areas. We determined area, number of parking spaces, annual solar radiation exposure, as well as possible obstructions or topographical concerns, such as hills. This resulted in data that allowed us to estimate total energy production for each parking area.

Next, we created a list of questions and sought out solar installation companies, campus sustainability faculty and staff, and other solar experts. We used these interviews to fill in gaps in our knowledge or otherwise confirm our existing research and propositions. We interviewed two solar installation companies (Select Energy and Revision Energy) as well as Dr. Paul Mathisen, the Director of Sustainability at WPI, Ms. Elizabeth Tomaszewski, the Associative Director of Sustainability at WPI, and Mr. James Dunn, a WPI alumni with extensive knowledge and experience in the solar industry. We also interviewed Ms. Jessa Gagne, the Director of Sustainability at Stonehill College.

Combining our online research with information gained from these interviews, we were able to better understand and estimate installation costs, as well as funding options for solar at WPI. We also took area and pathfinder radiation measurements for potential solar locations on campus. We were then able to synthesize this information into our cost/benefit analysis, which we used to estimate total cost, repayment period, and other non-monetary benefits of solar canopies. We found that a T Support canopy located in the North Lot at Gateway would be the most feasible option for such a system at WPI. It is recommended that WPI use a Power Purchase Agreement (PPA) to fund this system at minimal upfront cost to the school. This system would save WPI an estimated $1.3 to $2.6 million over the course of 20 years, the typical time period before ownership of the system is turned over to the university. All of this culminated in the creation of a design catalog of the best options for such a system at WPI, as well as the presentation of our major findings at the Sustainability Plan Community Update.

Chapter 1: Introduction

Renewable energy sources are a key component in combating climate change and supporting sustainable practices. Unlike nonrenewable energies, such as coal or natural gas, renewable energies do not produce harmful emissions and greenhouse gases. By 2040, global electricity demands are expected to raise by 70% as population increases and developing countries modernize (Acciona, n.d.). Globally, renewable energy use has been on the rise - up to about a fourth (26.5%) of global electricity production came from renewable sources such as hydro, wind, biomass, and solar power in 2017 (Renewables Global Status Report, n.d.). These complex global issues of climate change and an increased electricity demand can both be addressed with further promotion and development of renewable energy.

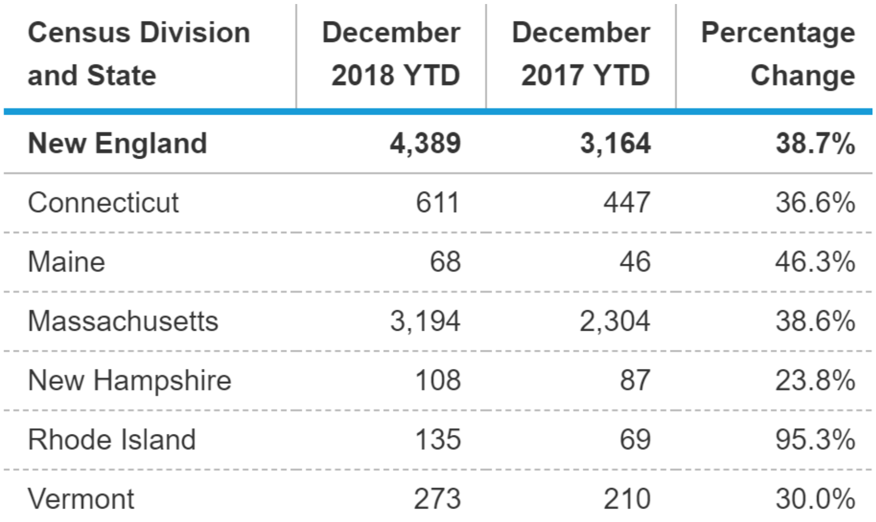
Climate change and electricity demand also have impacts on a local scale. Over the past decade, solar energy generation has risen dramatically in the state of Massachusetts, largely due to a rise in economic incentives. Many of these incentives such as the SMART program and MACRS are still available, yet Worcester Polytechnic Institute (WPI) has yet to take advantage of them, despite the fact that many other college campuses such as Stonehill, Endicott, and Harvard have. In contrast to the global 26.5%, WPI only sources 13% of its electrical energy from renewable sources - about half of the global average (Worcester Polytechnic Institute OP-6: Clean and Renewable Energy, n.d.). In addition, 0.1% of this is generated on campus. Although WPI has taken many steps in promoting sustainable practices - which includes ample recycling opportunities, waterless urinals, Leadership in Energy and Environmental Design (LEED) certified new construction and more. Their progress in on-campus sustainable energy amounts to just a few solar panels used to partially heat the fitness center pool. The institution has a multitude of parking lots and garages, which are optimal flat locations to install solar panels utilizing a solar canopy. This is especially effective in an urban environment such as Worcester, providing an efficient use of space for both parking and energy generation. Such a system could provide renewable energy to the school while providing additional benefits such as shielding vehicles from the elements, reducing plowing and repavement costs, and potentially providing added electric vehicle charging stations.

Figure 1 - A Typical Solar Canopy System (Baja Carports, 2018)

The goal of this project was to assess the feasibility of installing a solar canopy system over one of WPI’s parking areas, and develop a recommendation for the most effective option, supported with an in-depth cost/benefit analysis. Research was done to understand similar solar canopy installations, potential incentives, and relevant local policies. A location analysis was also done on site at WPI’s various parking locations, where area, solar radiation, and potential obstacles were considered. A number of interviews were also conducted with both solar installation companies and regional colleges with existing solar canopy systems. Through this, installation costs, project timelines, and best practices were better understood. These estimated installation costs were combined with researched energy costs, incentive amounts, and location analysis to create extensive cost/benefit analysis for the various canopy and location options around campus. These results were ultimately synthesized into a catalog of optimal solar canopy options on campus, and presented at the Sustainability Plan Community Update held on 23 April 2019.

Chapter 2: Background

Currently, the state of Massachusetts is a leader in the adoption of solar energy, largely due to its aggressive target goals and numerous incentive programs. The state's original goal of 250 MW (Megawatts) installed for 2017 has since been increased to 1,600 MW installed for 2020, a goal which was met early. As of 2018, approximately 3,200 MW has been installed with an additional 1,600 expected over the next 5 years (Solar Energy Industries Association, 2018). Despite its smaller area and lower solar potential than many southern states, Massachusetts ranked 7th out of 50 states in total solar generated in 2018, and dominates the New England theatre by generating 72% of the region's total solar power (Figure 2) (U.S. Energy Information Administration, 2019, February 27).



Census Division and State	December 2018 YTD	December 2017 YTD	Percentage Change
New England	**4,389**	**3,164**	**38.7%**
Connecticut	611	447	36.6%
Maine	68	46	46.3%
Massachusetts	3,194	2,304	38.6%
New Hampshire	108	87	23.8%
Rhode Island	135	69	95.3%
Vermont	273	210	30.0%

Figure 2 - New England Solar Generation by State in Thousand Megawatthours (U.S. Energy Information Administration, 2019, February 27)

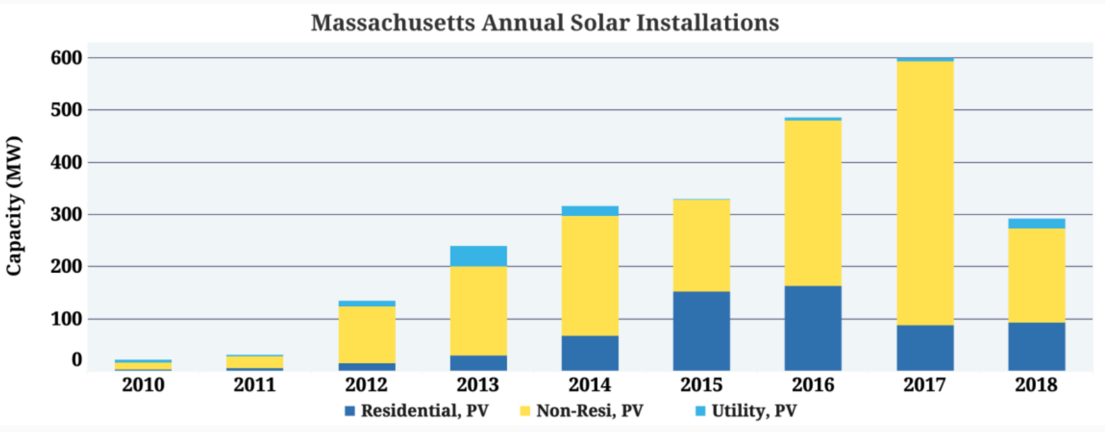


Figure 3 - Massachusetts Annual Solar Installation Capacity (Solar Energy Industries Association, 2018)

Of the state's total electricity generation, 11.4% came from solar in 2018 - up from 7.7% in 2016 (U.S. Energy Information Administration, 2019, February 27). In addition, Massachusetts has consistently installed at least 200 MW of solar power annually, with the majority coming from non-residential sites (Figure 3). Compared to this, WPI only sourced 1.11% of its electricity from solar energy sources in 2017 (with about 13% coming from other renewables) - with only a 0.1% of this generated on campus (Worcester Polytechnic Institute OP-6: Clean and Renewable Energy, n.d.). Many other colleges have participated in this statewide surge of solar installation, including Stonehill, Endicott, Harvard, and many more. WPI has not been one of these colleges, despite potentially profitable statewide incentives and the college's position as a leader in emerging technologies. In-depth reasoning for exactly why WPI should increase its on-campus solar generation is discussed below.

2.1 Importance of Renewable Energy

Renewable energy is an important area of sustainability primarily due to its environmental benefits, domestic jobs promotion, and energy security. Despite some vulnerabilities of their own, sources such as wind and solar power can be produced on a more local level, which can make them more reliable than a foreign oil or gas dependence. Renewable energy sources do not run out, and will continue to provide energy from natural phenomena such as the wind or sun that will not diminish over time in the same way that oil or natural gas will. In addition to its perpetual nature, renewable energy is also much "cleaner" than nonrenewable sources, as it does not emit environmentally harmful or toxic emissions, although certain renewable sources still have significant environmental impacts, such as water use and hazardous construction materials for a solar energy system (Union of Concerned Scientists, 2015). Renewable energy also tends to promote growth in the domestic job market, as the infrastructure can be built, maintained, and distributed locally as opposed to the international oil trade often subject to embargos or other complex issues.

2.2 WPI’s Renewable Energy Efforts

WPI has many pledges, programs, and efforts towards sustainability. This includes a formal sustainability plan, as well as a dedicated office of sustainability (Sustainability, n.d.). Some examples of recent sustainable efforts include LEED certified new buildings, efforts to promote waste reduction, reusable trays, waterless urinals, and the use of artificial light when possible. WPI has even invested in renewable energy for other schools. Most notably, they were heavily involved in the funding for a wind turbine at Holy Name, a local Worcester high school (Moulton & Moulton, 2017, October 05).

Figure 4 - WPI Sponsored Wind Turbine at Holy Name High School (Moulton & Moulton, 2017, October 05)

The efforts of the office of sustainability, combined with some off-campus renewable energy initiatives, show that WPI has an interest in promoting such practices. However, when it comes to on campus renewable energy, WPI has few achievements.

The majority of data on WPI’s use of renewable energy is sourced from a 2017 report from the Sustainability Tracking and Rating System (STARS), which analyzes and scores different parties based on their energy usages. The key statistic, is again, the fact that only 13% of WPI’s electrical energy usage comes from renewable sources - well below the global average. In 2017, WPI was given a score of 0.01/4.00 in the Clean and Renewable Energy category.

Worcester Polytechnic Institute
OP-6: Clean and Renewable Energy

Status	Score	Responsible Party
✓	0.01 / 4.00	**Liz Tomaszewski** Facilities Systems Manager/Sustainability Coordinator Facilities Department

Figure 5 - WPI's lackluster STARS renewable energy score as of 2017 (Worcester Polytechnic Institute OP-6: Clean and Renewable Energy, n.d.)

This same report states that WPI produces 332 MMBtu (million British Thermal Units) of its renewable energy on campus - only 0.1% of its total. This energy is created from 50 solar thermal panels on the roof of the WPI Sports and Rec Center. The main purpose of these panels is to heat the institution's pool through a heat exchanger. On average, however, these panels only meet 42% of the pool's energy needs (Worcester Polytechnic Institute OP-6: Clean and Renewable Energy, n.d.). WPI does purchase about 1.11% of its total electricity use from off site solar, which is not insignificant - this amounts to approximately 2,400 MMBtu. WPI is also well below the Massachusetts average of electricity sourced from solar (11.4%), at only 1.11% (U.S. Energy Information Administration, 2019, February 27). These figures should make it clear that although WPI has some dedicated sustainability efforts, it can improve upon its usage and promotion of renewable energy.

2.3 Solar Energy at WPI

As mentioned previously, WPI's only current use of renewable energy is a solar panel system on the roof of the Sports and Rec Center for heating the pool. In addition, WPI's sustainability plan outlines mandatory LEED certification of all new buildings (Orr, Tomaszewski, MacDonald, Pollin, Engbring, 2012). This demonstrates that the institution's administration understands and is willing to pursue renewable energy on campus. As for specific forms of renewable energy, there are very few that have concrete feasibility to be implemented. Sources such as hydroelectric are very location-dependent and cannot be utilized specifically on our campus. There are no rivers or lakes on campus, which makes hydro infeasible, not to mention that the construction of such a system would be significant. The implementation of a geothermal energy system is usually more beneficial close to tectonic plates; yet it could potentially be implemented successfully in regions such as Massachusetts (U.S. Energy Information Administration, 2018, December 19). This technology is complex however, and generally involves drilling and testing for geothermal reservoirs, which may not be located close to WPI's campus. The two systems that can be implemented with less dependency on location are wind and solar. A wind turbine is a something that can be utilized to great extent on WPI's campus, which is located on a hill in the city of Worcester, however the turbine and units for the energy's storage would need a dedicated space, which is not something WPI specifically has an ample amount of. As far as energy efficiency, a wind turbine is more efficient than solar and also emits less carbon dioxide to the environment (Boxwell, 2019). However, the implementation of a photovoltaic (PV) solar panel system would be much more cost-effective, especially for a university budget that affects the entire community including administration, staff, and student body. Solar energy is also very clean - the table below compares grams of CO_2 emissions produced per kWh of electricity produced.

Table 1 - CO_2 Emissions from Coal, Natural Gas, and Solar (Solect Energy, 2019, March 28)

Coal	800 - 1,050 g CO_2 / kWh electricity produced
Natural Gas	450 g CO_2 / kWh electricity produced
Solar	**60 -150 g** CO_2 / kWh electricity produced

Solar power emits substantially less CO_2 emissions than natural gas or coal. Furthermore, solar panels are much easier to construct and have a lot more flexibility as to where they are put, like on a building, parking garage, or canopy over a parking lot (Boxwell, 2019). It is for these reasons why a solar canopy system is the most feasible option to implement at WPI with respect to its other renewable counterparts.

2.4 Solar Incentives and Programs

Massachusetts has set ambitious statewide solar goals of 250 MW for 2017 and 1600 MW for 2020, and has surpassed both of these goals years ahead of schedule (Solar Energy Industries Association, 2018). This can largely be attributed to the state's effective incentive programs aimed at promoting solar generation. It is worth noting that in recent years some of these programs have been discontinued - most notably the popular net metering policy as well as Solar Renewable Energy Certificates (SREC-II) - however, there are still many active programs. According to the Database of State Incentives for Renewables & Efficiency (DSIRE, founded & funded by the US Department of Energy), there are a total of 82 financial incentive programs for renewable energy in Massachusetts, with 47 of these aimed at commercial developments (DSIRE, n.d.). As a large institution, WPI would fall into the commercial category of solar production. However, since they are a nonprofit, they would not be eligible for programs such as the Federal ITC unless they partnered with a for-profit organization. The effect of these programs specific to WPI is further explored in section 4.3. A number of the most popular and applicable of these programs are described in detail below.

2.4.1 Federal Income Tax Credit

The Federal Income Tax Credit, or Energy Investment Tax Credit (ITC) has evolved a number of times over recent years, with incentives varying depending on the specific type of renewable energy as well as its intended use. To be eligible for this program, the system must be constructed by a for-profit or commercial institution - meaning a nonprofit such as WPI would need to partner up to take advantage of this credit. For solar photovoltaics, the program offers an initial tax credit amounting to 30% of the cost of purchasing the system up until 2019, where the incentive drops off to only 10% by 2022 (DSIRE, n.d.).

Technology	12/31/16	12/31/17	12/31/18	12/31/19	12/31/20	12/31/21	12/31/22	Future Years
PV, Solar Water Heating, Solar Space Heating/Cooling, Solar Process Heat	30%	30%	30%	30%	26%	22%	10%	10%

Figure 6 - Annual Tax Credit for Solar PV Systems (DSIRE, n.d.)

2.4.2 Solar Massachusetts Renewable Target (SMART)

The popular SMART program is a replacement for the recently phased out SREC-II's, or Solar Renewable Energy Certificates. SREC-II's were preceded by SREC-I's, both of which gave credit directly to homeowners or businesses - in contrast to the new tariff based SMART program. SMART incentives are paid directly from the utility company (must be Eversource, National Grid, or Unitil) to the owner (Massachusetts Department of Energy Resources, 2019). To utilize SMART incentives, applicants must submit an application and await approval from the Massachusetts Department of Energy Resources (MDOER). Factors involved in determining the incentive amount are system type, size, distribution company service territory, customer rate class, and capacity block. In addition, SMART has a solar canopy "adder option" that pays an additional $0.05/kWh, which declines at a rate of 4% of a determined block period (Massachusetts Department of Energy Resources, 2019).

2.4.3 Excise Tax Deduction/Exemption

Massachusetts also offers a tax deduction program that allows owners to deduct all expenditures from the installation of a solar power system from their "net income, for state excise tax purposes" (DSIRE, n.d.). In addition, this system is also exempt from the tangible property measure of the state's excise tax. In fact, this exemption is in effect for the length of the depreciation period of the panels, not just for the year in which they are installed (DSIRE, n.d.). These tax deductions and exemptions would lessen the financial cost of such a system to universities such as WPI.

2.4.4 Modified Accelerated Cost Recovery System (MACRS)

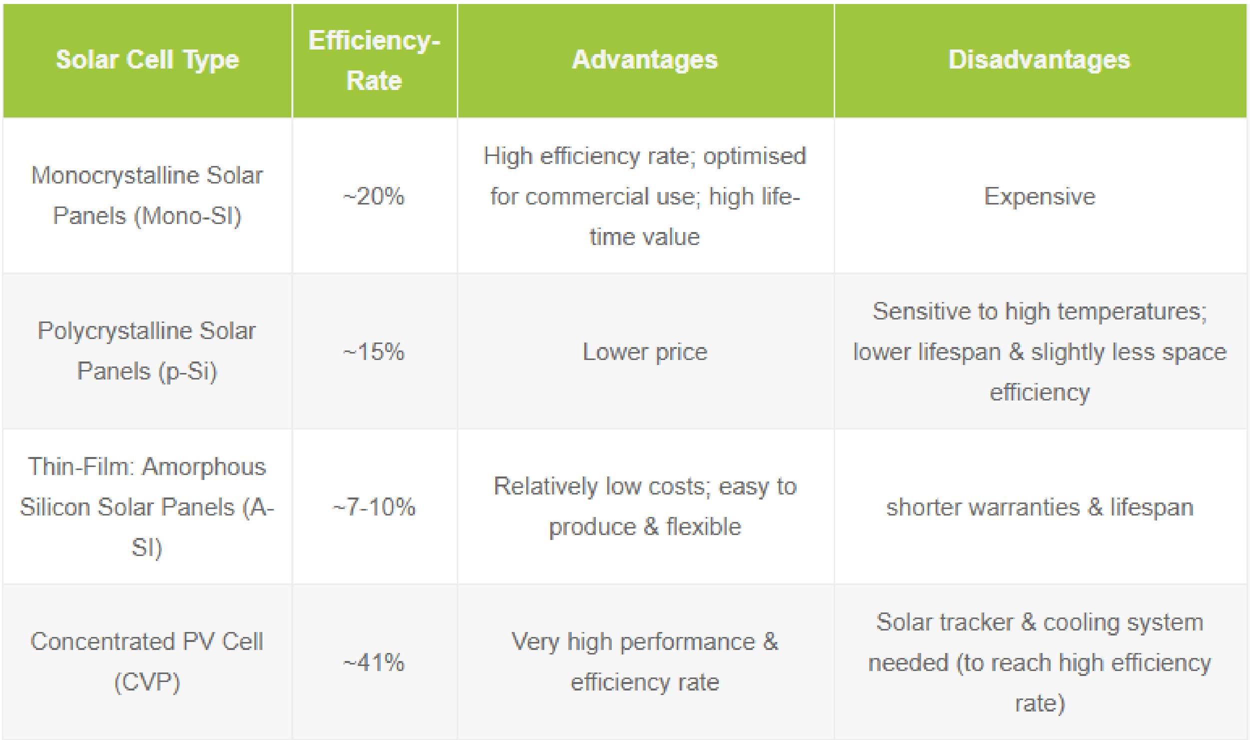
MACRS is a depreciation method in which a certain investment in property can be recovered for tax purposes over a specified period (Solar Energy Industries Association, 2019). Since solar energy can also be claimed under the income tax credit (ITC), the system would be eligible for a cost recovery period of 5 years, with an 85% deduction from the owner's tax basis. This incentive creates an accelerated rate of return on the system, therefore making it more economically attractive.

2.5 Types of Solar Energy Systems

Solar energy systems are very flexible in their implementation, and there are multiple setup configuration options for the panels that each have their own benefits. The two main configurations of solar that are used today are grid-tied systems and off-grid systems. A grid-tied system is one that is connected to the existing electric utility grid and to the specific structures it is used to help power. The utilization of a connection to the grid would remove the obligation to purchase batteries to store any generated energy. Another advantage of an grid-tied system is the ability to net-meter the power production and consumption, in which excess energy that is produced can be sold back to the utility (National Grid, 2019). However, as of April 2016, a statewide cap has been placed as to how much power can actually be metered: 7% for private entities and 8% for public. Furthermore, it is unlikely WPI will be able to produce more energy than it consumes, so it can not take full advantage of this benefit. The grid-tied system has fewer required components and provides a low cost in comparison to other options. In contrast to this the off-grid system is completely disconnected from the utility grid and requires batteries in order to properly store the energy created by the system. For smaller applications or in areas where it becomes more expensive to connect to the grid, this system is more practical.

2.6 Types of Solar Panels

There are different types of PV solar panels that each have their own advantages and disadvantages for different applications. The most common option for major commercial installations are Monocrystalline (Mono-SI) panels because they have higher efficiency ratings in comparison to most other options. The reason for this, is because they consist of a high purity silicon, which also allows for a higher power output. The Mono-SI panels are also more resilient to high temperatures and tend to have a longer life span versus other types, while also being relatively space efficient. These first generation panels are the traditional type of panel, along with its Polycrystalline counterpart, which is less expensive, but has a lower efficiency and shorter lifespan. As far as second generation solar panels, the Thin-Film solar cells are generally the cheapest available, and are the easiest to manufacture based on its triple-layered “thin-film” technology. As shown in Figure 6, these panels however have a very low rate of efficiency in comparison to the aforementioned first generation options, and even though they aren’t as sensitive to higher temperatures compared to the Polycrystalline, they do still have a very low lifespan. One of the newer third generation solar panel types, are the Concentrated PV Cell panels, which have the ability to operate at efficiency rates over 40%. Even though these panels have such a high performance, they have very specific needs based on location, additional cooling systems, and the fact that they must be positioned at the perfect angle to face the sun, all constraints which hinder the ability to be utilized as a solar canopy (GreenMatch, 2018, December 17).



Solar Cell Type	Efficiency-Rate	Advantages	Disadvantages
Monocrystalline Solar Panels (Mono-SI)	~20%	High efficiency rate; optimised for commercial use; high life-time value	Expensive
Polycrystalline Solar Panels (p-Si)	~15%	Lower price	Sensitive to high temperatures; lower lifespan & slightly less space efficiency
Thin-Film: Amorphous Silicon Solar Panels (A-SI)	~7-10%	Relatively low costs; easy to produce & flexible	shorter warranties & lifespan
Concentrated PV Cell (CVP)	~41%	Very high performance & efficiency rate	Solar tracker & cooling system needed (to reach high efficiency rate)

Figure 7 - Advantages and Disadvantages of Specific Types of Solar Panels (GreenMatch, 2018, December 17)

2.7 Canopy Support Options

The solar panels themselves are only one component of a solar canopy - the other key component is the canopy support. Different designs prioritize low cost or maximum area coverage, while others prioritize efficiency. Different supports may also be more or less desirable depending on the orientation of the parking area or parking spaces. The most popular support designs are shown below with a brief description.

2.7.1 T Support

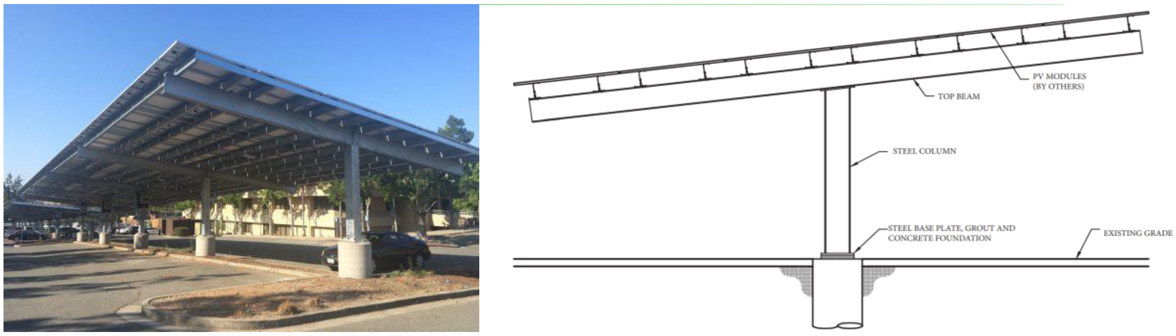


Figure 8 - T Support Design (RBI Solar, 2019)

The T Support canopy is one of the simpler and more cost-effective design options. The supports can be flat or oriented at an advantageous angle. These supports work best when anchored between a double row of parking spaces, and typically utilize one steel column per beam.

2.7.2 Truss

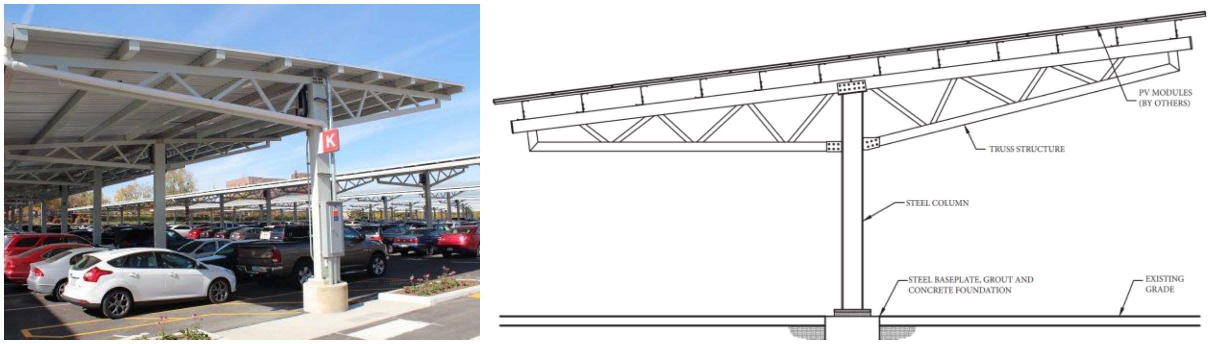


Figure 9 - Truss Support Design (RBI Solar, 2019)

A truss canopy is nearly identical in design to a T support, however its additional truss elements make it a sturdier design capable of holding heavier loads. This is advantageous in environments where heavy snow is a possibility, such as at WPI. Although the added supports would increase the cost, the system would be able to handle heavier loads and therefore be safer.

2.7.3 Long Spanning

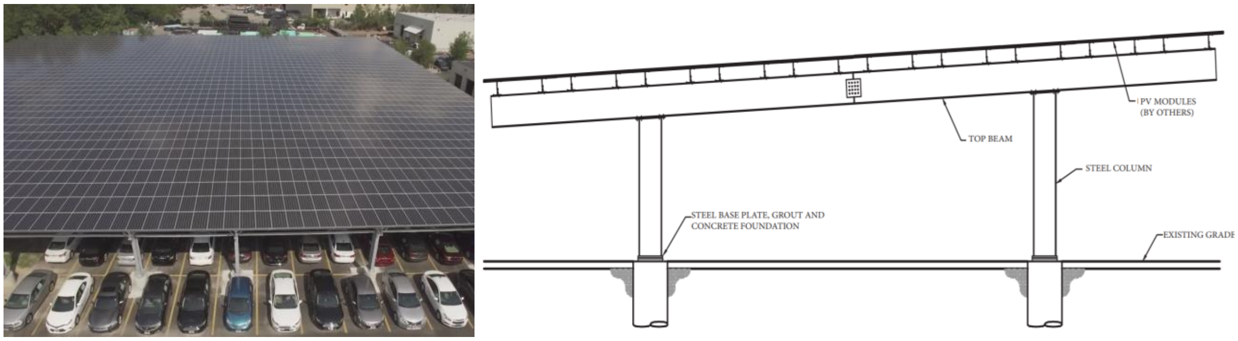


Figure 10 - Long Spanning Design (RBI Solar, 2019)

Unlike the previous two designs, the long spanning design covers both the parking spots and the aisles of a parking lot. These designs often use two or more support columns per beam, since the beams are much longer. Although larger and more complicated supports will likely increase the cost, the system will also generate more energy since the panels are able to cover a much larger area, resulting in a greater return on investment.

2.7.4 Inverted

Figure 11 - Inverted Design (RBI Solar, 2019)

An inverted canopy design is unique in that it is made up of two different rows of angled panels per support. This enables the system to increase its overall efficiency by capturing energy from two different ideal angles. This design could also be potentially useful for better dealing with snow accumulation, as the panels could be angled in such a way that the snow would slide towards the middle of the canopy as opposed to off of either end. This would reduce the risk of injury or damage to pedestrians or vehicles, however, the snow would need to be removed to expose the panels to the sun - potentially increasing maintenance costs. Some local examples of inverted canopies can be found at Miscoe Hill Middle School in Mendon, MA, and at UMass Amherst (UMass Amherst, 2019).

2.7.5 Garage

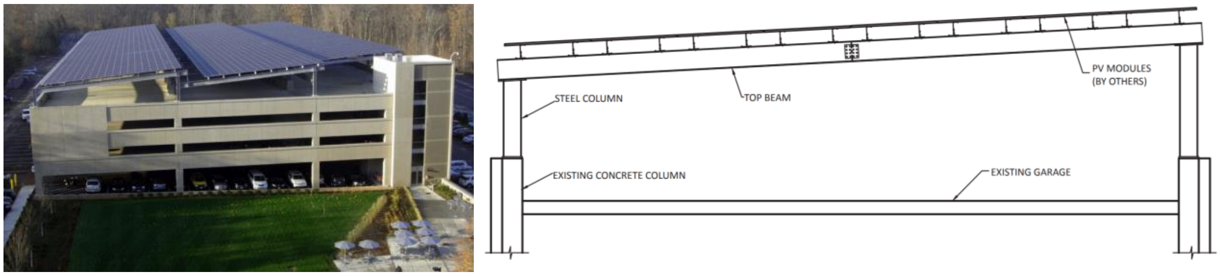


Figure 12 - Garage Structure Design (RBI Solar, 2019)

The garage panel design is tailored to fit the existing architecture of a parking garage. This may include taking advantage of existing concrete supports or using lightweight materials to lessen the load on the structure. One example of a local parking garage canopy can be found at the Staples HQ in Framingham, MA, shown in Figure 12.

2.8 Solar Panel Canopy Considerations

Additional factors that are taken into account when looking to install a solar panel canopy include safety, warranty policies, and potential alternative uses. Safety must be addressed for the protection of pedestrians interacting with the structure and is an important component of the planning process. Warranties must also be considered, should there be any mechanical or environmental issues that would impact the energy generated or cause damage to the system. Finally, studying additional applications, such as coupling charging stations for electric vehicles, would help WPI maximize its use of the canopy system.

2.8.1 Safety

The overall safety specifications concerning solar panel canopies are often dependent on the design chosen. Solar canopies that have been permanently established, and whose structure is made of stainless steel, are considered safer options than those that could be mobile or are made from another material. Solar canopies can provide shelter to vehicles and pedestrians during inclement weather. They are also more safe for animals in local ecosystems, because the amount of road salts that have to be used is reduced. Projects commissioned by a licensed and reputable company will meet safety standards, and ensure that the structure can handle the elements, such as temperature disparities, windy conditions, and excessive snow. The structure itself will have an expected amount of weight it can bear, to which snow may not be problematic. Built up snow, however, should be removed if the weight becomes an issue, or if there danger that it could slide off and hit pedestrians or vehicles, as there would be potential for injury or damages. The solution to snow build up involves removing the snow in a controlled manner. The design also impacts the likelihood of falling snow, such that the inverted design would allow snow to collect in the middle, thus the risk of it sliding off is more minimal compared to the T Support design. This is due to the fact that the T Support is pitched, and therefore would increase the probability that snow would fall down the slope. This issue can be managed with rails to prevent the snow from falling. Routine checks should also be made to continually assess the viability of the structure. Additional safety factors would need to be addressed if a canopy system were to be built on a parking garage, as it would need to be ensured that the parking structure could support the weight of the canopy system.

2.8.2 Warranty

While warranties vary by panel type and company, there are general factors that should be kept in mind. First, many warranties are valid only when there are records of proper maintenance. There are a few types of warranties, including performance and equipment. A typical warranty for performance is for 10-25 years, and it ensures production of at least 90% initially, and decreases to no less than 85% production over time. Equipment warranties usually involves a period of 10-12 years and states that the solar panels will be functional, and accounts for any issues with the manufacturing. The equipment warranty considers factors such as defects, impact from the environment, or other abnormalities. If WPI will be investing thousands of dollars, having a reliable and a long lasting warranty on the panels placed on the canopy will ultimately reduce costs should the panels need to be replaced, though costs may also increase with required maintenance to keep warranties active (Energysage, 2019, January 02).

2.8.3 Potential Applications - EV Charging Stations & Water Conservation

Electric vehicles (EV) are becoming increasingly popular in the United States and are supported by the Department of Sustainability at WPI. In the first part of 2017, 91,000 new EVs were registered in the US. This increased 35% in the first half of 2018, to more than 123,000 newly registered EVs in the US (Reichmuth, 2019, September 06). To accommodate this growing trend, WPI installed 3 EV chargers with 6 available charging ports for students and staff in the Park Avenue Garage. One potential application of installing a solar panel canopy includes utilizing the power generated to increase the amount of charging stations on campus, and to supply them with the green energy produced. Currently, the charging stations at WPI are first come first serve. There is no guarantee chargers will be available, and there is no enforced time limit for charge sessions, despite the popularity of the initiative (Electrical Charging Stations at WPI, 2018, June 05). At WPI, there are an average of 200 charges a month and charging sessions are free. It’s estimated that approximately 45 drivers use the chargers in a given month and more than 155,000 miles have been powered by this project (Sustainability Report 2017-2018 – Transportation, 2019, March 21). Coupling EV chargers and a potential canopy could be useful for the WPI community based on the interest in the system already in place.

Solar panel canopies can also be adapted to capture rainwater or melted snow and store it. The water conserved is often is used for irrigation. The angle of the design chosen determines the flow of the water into the storage, which funnels into a system for later use. The solar panel canopy would need to be water-tight for the system to work. This feature would help provide protection from droughts, such as the one Worcester has recently experienced. Water conservation would be a possible additional application to implementing a canopy on campus, though ,making the system watertight would ultimately increase overall costs (Casey & Cardoso, 2018, October 08).

2.9 Case Study - Typical Approach to a Feasibility Study

Typically, the problem of providing renewable energy sources in an urban environment is first addressed by deciding on the most cost and energy efficient energy source. Next, a suitable area must be found. In a case study for solar feasibility, the most appropriate parking lot or garage should be chosen by weighing the pros and cons of each option. These may include total area, access to the sun, and effect on existing structures or infrastructure. And perhaps most importantly, the upfront cost compared to the time period in which the panels will pay for themselves was read as background information for our project.

In a solar feasibility study done near Fairbanks, Alaska, they had already decided that solar was the best option as it was the most feasible renewable option for single family on grid residences (Gruau, 2008). Their process was divided into three steps - an initial site survey, a basis for their cost/benefit analysis, and a final payback and life cycle cost analysis. This process is outlined below.

2.9.1 Initial Site Survey

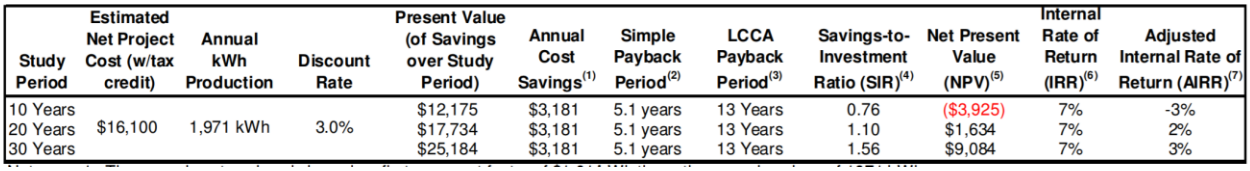
An initial site survey is the first step in conducting a typical solar feasibility study. Area and potential obstructions are noted, particularly obstructions in the south facing direction. A database such as National Renewable Energy Laboratory (NREL) is then used to analyze average weather and solar radiation patterns for the general region. Depending on the system, it may also be feasible to adjust the angle of the panels to capture solar radiation better at different times of the year. In this case study, they found these angles to be 52 and 90 degrees to the horizontal, due to the fact that Alaska is over 4,000 miles from the equator (Gruau, 2008). This made it necessary for the panels to be adjustable to capture optimal sunlight in both the summer and winter months. In more southern regions, this range is usually much smaller, making it more practical to use fixed panels, which are more inexpensive.

2.9.2 Cost/Benefit Analysis Basis

In the Fairbanks case study, an exact system and location was not determined as the study was for a general area and not for a specific home or structure, however, typically installation costs would be covered here in the form of a quote or estimate from a solar installation company. Total construction time would also be estimated. Energy generation estimates as well as potential savings due to local incentive programs are also discussed. In this example, a local program called Sustainable Natural Alternative Power (SNAP) was examined (Gruau, 2008). This program gave payments adjusted by year for the total kWh of energy generated using the solar system.

2.9.3 Final payback / Life Cycle Analysis

This final step ultimately determines whether the solar system will be feasible, at least in the economic sense. This is done by determining the payback period of the system - the shorter, the better. The primary factor in determining payback is the amount of annual savings subtracted from the installation cost of the system. However, the amount calculated is not the only factor. Solar panels degrade over time, and inverters also need to be replaced - in addition, there is the additional possible maintenance cost of snow removal from a canopy system.



Study Period	Estimated Net Project Cost (w/tax credit)	Annual kWh Production	Discount Rate	Present Value (of Savings over Study Period)	Annual Cost Savings(1)	Simple Payback Period(2)	LCCA Payback Period(3)	Savings-to-Investment Ratio (SIR)(4)	Net Present Value (NPV)(5)	Internal Rate of Return (IRR)(6)	Adjusted Internal Rate of Return (AIRR)(7)
10 Years	$16,100	1,971 kWh	3.0%	$12,175	$3,181	5.1 years	13 Years	0.76	($3,925)	7%	-3%
20 Years				$17,734	$3,181	5.1 years	13 Years	1.10	$1,634	7%	2%
30 Years				$25,184	$3,181	5.1 years	13 Years	1.56	$9,084	7%	3%

Figure 13 - Sample Cost/Benefit analysis for solar implementation in Fairbanks, AK (Gruau, 2008)

The main deliverable of the Fairbanks Solar Feasibility Study is shown in Figure 13. Estimated project cost, savings, and repayment period are some of the key components. Analysis was done for three study periods of 10, 20, and 30 years, in order to better understand both short and long term effects. The savings to investment ratio (SIR) of these periods were 0.76, 1.10, and 1.56 respectively, displaying the increase in overall savings after the 13 year repayment period. The Fairbanks region was deemed feasible for solar, however it was recommended that a tax professional be contacted in order to ensure the business or homeowner qualifies for the incentive program (Gruau, 2008).

2.10 Models for Solar Energy use on College Campuses

Stonehill College and Endicott College are good model systems for WPI because they are located in Massachusetts - meaning they installed their canopy systems in a similar social and economic environment to WPI. Their installation companies and incentives could be the very same WPI uses in the future. Hampshire College is also a good model in that it has 20 acres of solar panels, as well as a canopy on a roof. Hampshire College relies on 100% solar energy. The solar energy that they are unable to produce is purchased from other off campus solar farms. It is worth looking into how Hampshire College supplements its energy production, possibly as an alternative solution to the lack of renewable energy utilized on campus, should we find a canopy to not be feasible (Hampshire College, 2016). Rutgers University, while it is not in New England, produces the third most solar energy for a college campus in the US. The top producers for a college campus are in Arizona. Geographically speaking, Rutgers is more representative, and would be a good model for a large scale implementation, should we possibly conclude that multiple canopies would be most cost-efficient and effective. The canopies cover about 32 acres of parking lot, which was the largest installation on a college campus when it was built. In 2014, Endicott college unveiled a large solar panel canopy with 3,000 panels that provides enough energy to support the electricity for 3 of their dorms (The Salem News, 2014, May 06).

In October of 2016, Stonehill College began the construction of a solar panel canopy system covering their largest parking lot on campus that would have the potential to provide 2.8 MW of power to the school by the time of its completion in March of 2017 (Stonehill College, 2017, March 13). Before this project was implemented, the college had already put a large effort into prioritizing their sustainability efforts with a solar farm opening in 2014 consisting of over 9,000 panels. With the addition of the parking lot canopy that spans roughly 5 football fields in total area, over 20% of the school's energy usage is covered by renewable solar energy and is estimated to save them about 4 million dollars in energy costs over 15 years. Stonehill is located in Easton, Massachusetts, about an hour southeast of WPI's campus, so their benefit from a solar panel system is very comparable to that of WPI. Furthermore, Stonehill partnered with Solect Energy, the leading commercial installer of solar panels in the state which is based in Hopkinton, only 30 minutes from WPI. Representatives from both Stonehill, as well as Solect Energy, could be very beneficial to interview for more information about our project and the feasibility of its implementation. Though WPI's would be at a much lower scale, their project was completed only 2 years prior to this one, so there is high relevance in analyzing the type of panel used, installation details, and construction of the canopy for their system. All of this was very crucial information for our potential costs and energy production based on its overwhelming success.

Chapter 3: Methodology

The goal of this project was to assess the feasibility of WPI’s various parking areas for a solar canopy system, and develop a recommendation for the most effective option, supported with an in-depth cost/benefit analysis. We addressed the need for more sustainable energy use and conducted the following methodology to determine the feasibility of such a canopy in various parking areas at WPI.

We started by conducting background research and determined valid options for solar canopies on campus. We read case studies of similar solar feasibility projects, in order to better understand the typical methods and process of such a study. We then conducted location analysis on all the parking areas across campus. We combined this analysis with information gained from online research, interviews with solar installation companies, and WPI faculty. From our data collection, we created a cost/benefit analysis for each potential site. Our main deliverables were the creation of a catalog displaying our recommended designs and location options, and the presentation of our findings to the Sustainability Plan Community Update held on April 23, 2019.

Objectives:

1. Understand WPI’s Sustainability Structure as outlined in the Sustainability Plan
2. Read and analyze solar feasibility case studies and policies
3. Conduct location analysis to compile list of potential solar canopy options at WPI
4. Gain insight into the solar canopy installation process through interviews
5. Understand installation and maintenance costs of potential solar canopies at WPI
6. Analyze cost/benefit and return on investment of solar canopies on campus
7. Create a Design Catalog and final presentation

3.1 Understanding WPI’s Sustainability Structure

We assessed the feasibility of WPI’s various parking areas for a solar canopy system through a working knowledge of the associated sustainability organizational structure that we used to identify key members of faculty and staff. We achieved this understanding through reading the sustainability plan as well as conducting interviews. There were some individuals or groups that were integral to our completion of a successful project. We determined key groups and individuals to be:

- The Facilities Department at WPI - Grounds Management, Administration
- The Director of Sustainability at WPI- Dr. Paul Mathisen
- The Associative Director of Sustainability at WPI- Ms. Elizabeth Tomaszewski
- The Executive Vice President at WPI- Mr. Jeffrey Solomon

Facilities was an important consideration because they would be partially responsible for some of the canopy's required maintenance and related construction. The administration in the Facilities Department would play a major role in making the decision to implement a solar panel canopy system. The Director of Sustainability, Dr. Paul Mathisen, provided us with information on how our project could fit in at WPI, and how it might be perceived by the community. Dr. Mathisen referred us to the Associative Director of Sustainability, Ms. Elizabeth Tomaszewski, for inquiries regarding stakeholders we would ultimately need to present our ideas to for potential implementation. Ms. Tomaszewski provided us with contact information for those that would make the decision within Facilities. The Executive Vice President, Mr. Jeffrey Solomon, was another key stakeholder because of his responsibility for finance and operations, as our project would require monetary and administrative support. Mr. Solomon was also considered an important individual based on his contact with higher members of administration, including President Laurie Leshin and Board of Trustees. According to the organizational chart for sustainability at WPI, major communication lines exist between Facilities and the Director of Sustainability, and Executive Vice President and the Director of Sustainability. We attempted to understand the relationship between stakeholders and developed our proposal plans accordingly. We recognized main individuals or groups that would be most relevant to our project, and sought interviews based on that understanding (Sustainability, n.d.).

3.2 Analyze Case Studies and Local Policy

After investigating WPI's organizational structure and sustainability plan, our next step was to analyze similar case studies regarding solar feasibility, and understand potential solar incentives and policies.

Our reasoning for selecting case studies was to learn the best practices for what a feasibility study typically entails. We began with the feasibility study in Fairbanks, Alaska, discussed in section 2.9, and then analyzed a more local case - Stonehill College (also discussed in 2.10). This gave us a more local and recent example of the installation process of a solar canopy system. Understanding these two case studies proved very useful to our team, and much of our methodology was formulated based on these practices.

We also took note of various incentive programs and solar policies. We discovered 3 main routes in terms of financing - direct ownership, shared ownership with a partner, and power purchase agreements (PPA) - that should be considered as part of our analysis. Next, we organized potential incentive programs under each of these categories, as many of these incentives have certain requirements that must be met. We identified a number of incentives that WPI could potentially benefit from, including the Federal ITC, SMART, and MACRS which would later be investigated as part of our analysis. In summary, understanding best practices through case studies and being aware of available incentives was the next logical step for our team to pursue before conducting our location analysis in the field.

3.3 Conduct Location Analysis to Compile Potential Options at WPI

Along with reading similar case studies and understanding the methods of other renewable energy IQP’s, we conducted a solar location analysis on the WPI campus. To do this, we compared the advantages and drawbacks of different parking lots and garages across campus.

We started by holistically looking at all parking options that could potentially support a solar canopy such as the East Hall Garage, Hackfeld Lot, and Boynton Lot, etc. In each option, we used the following criteria to determine lots that could best support a solar canopy system, including: total area, exposure to sunlight and the elements, number of parking spaces, and the effect on parking. We also considered the proposal for a new building in the Boynton Lot, and how this might affect factors such as total area. To measure area, we first utilized the MassGIS mapping software to gain rough area estimates, as well as confirming these on the ground with a tape measure. By using two methods of measurement were able to verify that our data is accurate (Oliver MassGIS, n.d). We were able to verify our area measurements using AutoCAD software as well.

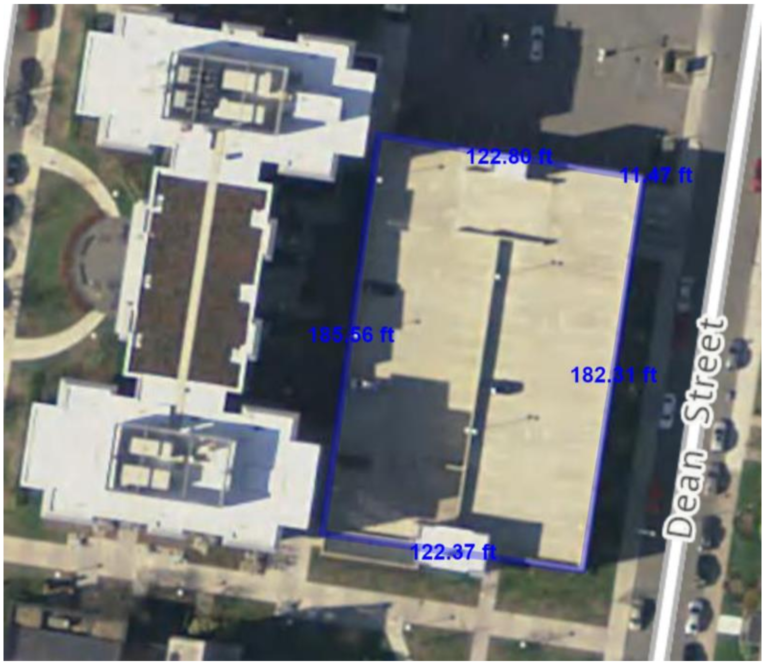


Figure 14 - Sample Image of the East Hall Garage using MassGIS's mapping tool (Oliver MassGIS, n.d)

Additionally, we used solar pathfinder equipment as well as obvious exposure (or the lack thereof) of sunlight to estimate which lots have the potential to generate the most solar energy. By setting up the pathfinder in a centralized location for each lot, we traced out the specific obstructions that would block out the sun over the course of the day. Based on these various obstructions, we deduced the average percent of daily solar radiation for each location by summing the radiation percentage for each month using the specific pathfinder sheet for every lot like in Figure 15.

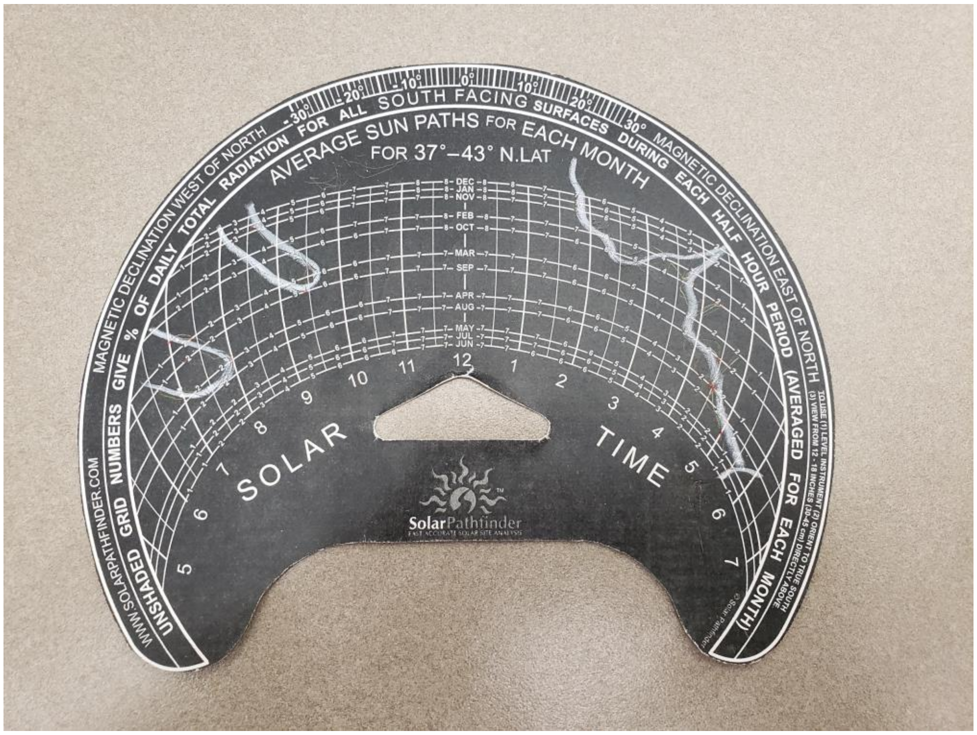


Figure 15 - Solar Pathfinder Sun Path Diagram

Following this, we conducted a more detailed analysis for our best options to get a better understanding and more accurate reading for the solar potential at these locations utilizing 4 additional readings centered in each quadrant of the various lots. We also analyzed public weather data for the city of Worcester, or Massachusetts in general, to determine the average number of sunny days and solar potential per year.

Once we established the most feasible locations for solar canopies with regards to area and solar potential, we then considered other factors that would impact their implementation. Some of these other factors included comparing different types of solar panels to determine the most cost-effective and efficient options. We also sought to determine the level of community exposure, based on how visible the potential location was to the public. Using the above information, the energy produced per unit area for each solar option was calculated using the National Renewable Energy Laboratory (NREL) website as well as other published literature (National Renewable Energy Laboratory, 2019). This location analysis was the first step conducting our final cost-benefit analysis, and ultimately helped us to decide on our best options.

3.4 Gain Insight into the Solar Canopy Installation Process

The main method we used to gain insight into the process of solar canopy installation involved interviewing local solar installers, sustainability staff from WPI and other institutions, and experts in the field of solar energy. We conducted formal research interviews with various external groups and individuals, such as Solect Energy, ReVision Energy, and the Director of Sustainability at Stonehill College, Ms. Jessa Gagne. Informal interviews were conducted with an expert, Mr. James Dunn, The Director of Sustainability at WPI, Dr. Paul Mathisen, and the Associative Director of Sustainability at WPI, Ms. Elizabeth Tomaszewski. We started with initial contacts and asked for referrals to other members or groups who were more specialized in answering our questions. Though we had ideally wanted to hold interviews face-to-face, we utilized both phone and email interviews to be more efficient, as some of the solar companies and colleges were not local.

We conducted two styles of interviews, formal and informal. Having definitive background data allowed us to ask questions more tailored to the specifications of each lot or garage. Some of the data we collected before our interviews included the areas of lots and parking spaces, as well as readings from the solar pathfinder. This information allowed us to obtain estimates and advice from the companies we interviewed. We followed protocols for conducting good interviews, for example, we asked questions that were ordered and grouped in a way that allowed for a logical flow of discussion topics. Furthermore, the structure of the questions themselves was not be phrased in a leading manner, so that all information received was as objective as possible (Research Methods Guide: Interview Research, 2018, September 21). Questions were mostly open-ended to get the most information, but also very clear in what was being asked. We created a set of preliminary questions for each set of interviews we completed (see Appendix F).

We then created an interview protocol. We initiated each interview by introducing ourselves, project, and major goals. We asked for consent to use any of the information we collected in our report or presentations. Furthermore, we determined how long the interview would take prior to the actual interview. We decided in advance how we wanted to cite the information obtained. If consented by the interviewee, notes were taken, but no interviews themselves were recorded. Overall, we followed the best practices for conducting the interview.

We were punctual, prepared, and thanked the interviewee for their time in each interview conducted (A Short Guide for Conducting Research Interviews, 2014, March).

We met with Mr. James Dunn, a WPI Alumni and expert in solar energy, on 26 March 2019 at 0800 at the Bean Counter, along with Professor Fred Looft (Dunn, 2019, March 26). We were referred to speak with Mr. Dunn through Professor Looft, and we arranged the interview via email. We spoke informally for about an hour over breakfast. We had a set of questions prepared, but found we did not need to ask all of them, because Mr. Dunn offered most of the information without prompting. We took notes despite it being more of an informal conversation where we received Mr. Dunn’s expert opinion. We thanked Mr. Dunn for his time, and he encouraged us to reach out if we would like a follow-up interview or any additional information or contacts.

We briefly spoke with Dr. Paul Mathisen, the Director of Sustainability at WPI, in his office on 09 April 2019 at 0900 (Mathisen, 2019, April 09). We decided against a formal interview, because the main goal of speaking with Dr. Mathisen was to get a sense of how our project would have been received by WPI. We took notes and found that Mr. Mathisen answered most of our questions without us having to ask. He referred us to speak with the Associative Director of Sustainability at WPI, Ms. Elizabeth Tomaszewski, regarding our contact with Facilities and request for information on how we could make a proposal to administration. We thanked him for taking the time to meet with us, and kept him updated on our progress.

We interviewed Ms. Elizabeth Tomaszewski, the Associative Director of Sustainability at WPI, on 11 April 2019 at 0900 in the Facilities Department building (Tomaszewski, 2019, April 12). We met briefly for approximately 20 minutes and asked her the prepared questions. She provided us contact information for many in the Facilities Department and also gave us her opinion on our deliverables. We took notes on her advice for our project. We thanked her for meeting with us, and she encouraged us to stay in touch.

We interviewed Ms. Jessa Gagne, the Director of Sustainability at Stonehill College and WPI alumni, (Gagne, 2019 April 09). We had initially reached out and attempted to schedule a phone interview. Ms. Gagne requested time to gather information for us, and opted to send us a reply via email instead. We sent her our questions and she sent us a PowerPoint detailing the implementation process, specifications, and pros/cons at Stonehill. She also provided us with a schematic of the design that was implemented. She encouraged us to reach out if we needed any additional information. Upon reading through the presentation, we were able to answer our questions, so we thanked her for the information, and politely declined the need for a follow up interview.

Lastly, we interviewed two solar panel companies to learn about specifications for installation. We interviewed ReVision and Solect Energy:

Solect Energy was chosen because they are based in Massachusetts and installed panels at Stonehill College. We made initial contact via email, and was referred to a representative. We interviewed the representative on the phone on 28 March 2019 at 1300 (Solect Energy, 2019, March 28). It was a formal interview and we stuck to the prepared questions, which were sent to him prior to the interview. We agreed to follow up with him, as he offered to send us a solar panel canopy cost estimator. We emailed him later in the week to thank him for the interview, and to confirm that he would send us the calculator, which he did.

We made contact with a representative of ReVision energy at the "Shaping the Future of Sustainability, Massachusetts Sustainable Communities and Campuses" Conference in Cambridge, Massachusetts on 29 March 2019 (Revision Energy Interview, 2019, April 10). The representative agreed to schedule a future interview. We reached out to them again with an email that included our interview questions. We had scheduled a phone interview for 03 April 2019 at 1600, but were unable to reach them. We sent an email explaining that we had called and received no response and that the representative could send the answers via email. We received answers to most questions in an email and were encouraged to call to receive any additional information we might need. We followed up with a brief phone interview on 10 April 2019 at 1600. We thanked the representative for his time.

3.5 Understand Maintenance and Installation Costs of Potential Solar Canopies at WPI

Based on our background research, we developed an understanding of the specific technology and costs regarding the installation of photovoltaic solar panels. We compared and discussed potential options with Solect Energy and Revision Energy to better gauge what commercial standards were the most feasible to implement in a solar panel canopy system. Suggested factors considered for such a system with respect to installation itself are the areas of the locations where the system would be implemented, the wattage and efficiency of the panels used, and total power of the system based on canopy type. These factors were considered during our analysis.

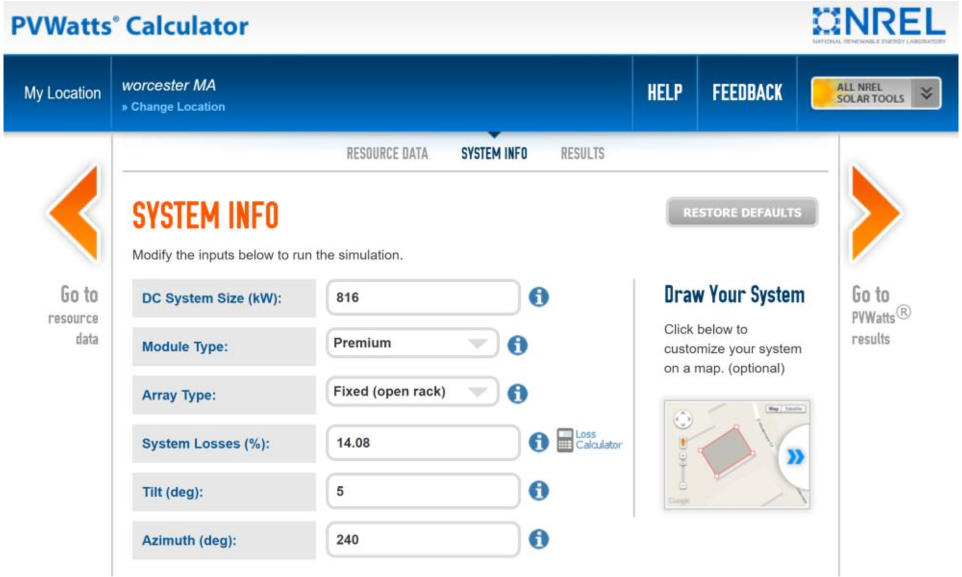
To assess the different aspects of the maintenance behind implementing a solar canopy system, we compiled online research along with information from various interviews. After speaking with the aforementioned installation companies, other schools who have implemented similar systems such as Stonehill, and the Facilities department at WPI, we were then able to configure a process for what would need to be done in order to maintain the system. This process would require responsibilities from both the company that installs the canopy and also the school itself, taking into consideration weather related needs such as snow removal. Many companies that install photovoltaic systems are the ones that perform the majority of the maintenance that goes along with it, but depending on factors like size and canopy type, the specific cost of this maintenance is also something we researched further to feed into our different cost analyses.

3.6 Analyze Cost vs. Benefit and Return on Investment of Solar Canopies on Campus

The different costs and benefits of the project and how a canopy system can be cost effective in the long run were essential to analyze in our feasibility study. Our team analyzed both monetary and nonmonetary costs and benefits. Our main process focused on comparing the costs of installation and maintenance with the benefits of reliable energy production and savings (PowerScout, Inc., 2017). Initially, we approximated the total power that would be provided from implementing a canopy based on the area of the location and type of design that would be constructed (Solect Energy, 2019, March 28). This was done using industry standards provided by various photovoltaic installation companies. Some of these standards include average cost and module sizes. These modules are categorized by number of parking spaces and the area that is accumulated by said parking spaces. Following this, we then calculated the cost of the system based on total power in kilowatts given different panels have different wattage ratings and the cost per watt varies depending on the type of canopy to be constructed, ranging from roughly $3.25 to $3.75 per watt. The total cost of the system will shift down based on the various incentive programs that are potentially available to WPI at both the federal and state level.

However, there are additional costs that had to be taken into consideration, made visible to us by certain installation companies. These are “due diligence costs” which include geotechnical evaluations, site planning, and specific canopy design drawings produced by the installation company (Solect Energy, 2019, March 28).

Through our process, we were able to shift from this cost analysis to calculate the monetary benefits of a solar canopy system. Based on the total power (in kilowatts) that the panels would provide found previously, we made use of the official energy production calculator from the National Renewable Energy Laboratory (NREL), that was also recommended to us in multiple interviews (National Renewable Energy Laboratory, 2019). This calculator, shown in Figure 16, takes into account the total system size (or power) of the system in combination with its location to determine average annual output in kilowatt hours. The efficiency of the panel, tilt, and azimuth (rotation with regards to the cardinal direction how the panels will be oriented), are all variables that also contribute to the energy that the specific system has the potential to produce. For a solar canopy system, the panels would be fixed and not adjustable, as they are part of the structure.



worcester MA

Modify the inputs below to run the simulation.

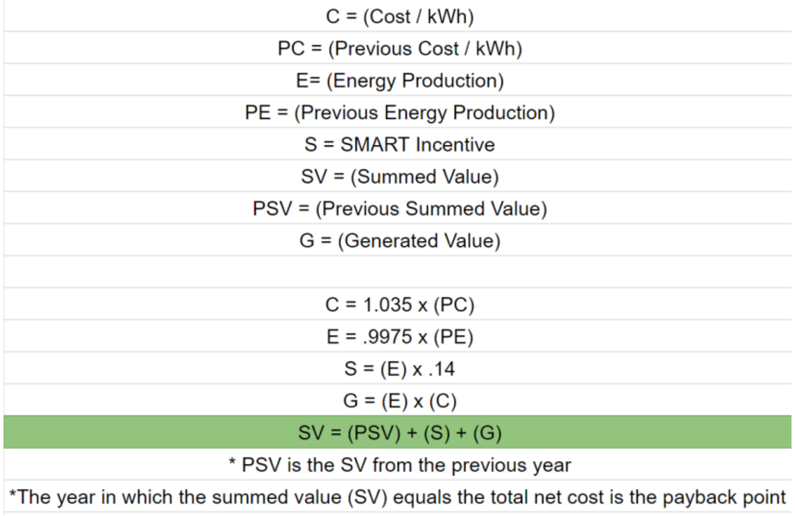
DC System Size (kW): 816
Module Type: Premium
Array Type: Fixed (open rack)
System Losses (%): 14.08
Tilt (deg): 5
Azimuth (deg): 240

Click below to customize your system on a map. (optional)

Figure 16 - NREL Solar Energy Calculator (National Renewable Energy Laboratory, 2019)

As a result of inserting our specific data collected into the calculator, it provided the total amount of energy in kilowatt-hours (kWh) that the system would produce over the course of one year. At this point, our Solar Pathfinder data was used to provide further accuracy in the total amount of energy produced. For each iteration of the NREL calculator used, we then multiplied the total energy by the average daily radiation percentage found in each lot using a solar pathfinder to account for energy losses due to obstructions.

The final part of our cost vs. benefit design process involved creating excel data sheets that combined our measured location analysis data, figures from solar companies, and NREL calculations to create a rough payback period estimate. We also accounted for the increase in energy costs over time, to address the fact that the annual revenue from a solar canopy system would become larger over time, despite the fact that the panels themselves will slowly degrade over their lifetime (Energysage, 2019). The excel sheet does the math for us, we just need to account for the correct multipliers and initial values. To do this, we first input our initial energy production, and multiplied this by a known degradation rate of most solar panels (-.25% a year, or .9975). This gave us an updated energy production for our system up until the warranty expires in the 25th year. Then, we multiplied this energy production by the cost of energy per kWh. This cost is $0.1894 in 2019, however it is expected to increase at a rate of 3.5% (or 1.035 multiplier) annually for the foreseeable future. This step gave us the generated value of energy produced by our system each year. This can be seen as our annual savings after the canopy system has passed its payback period. This process is visualized in Figure 17.



C = (Cost / kWh)
PC = (Previous Cost / kWh)
E= (Energy Production)
PE = (Previous Energy Production)
S = SMART Incentive
SV = (Summed Value)
PSV = (Previous Summed Value)
G = (Generated Value)

C = 1.035 x (PC)
E = .9975 x (PE)
S = (E) x .14
G = (E) x (C)
SV = (PSV) + (S) + (G)
* PSV is the SV from the previous year
*The year in which the summed value (SV) equals the total net cost is the payback point

Figure 17 - Payback Analysis Equations

To get the estimated payback period, we included a final column of the total generated energy value up until that point, titled “summed value”. This combined totals from both SMART incentives and generated energy value from all year up until that point. SMART incentives pay $0.14 / kWh (or .14 multiplier) of energy production. Knowing our estimate for the installation of the system, we then took note of which year this summed value exceeded our installation cost. Using this methodology, we were able to estimate payback periods for each canopy type, for each parking area.

3.7 Deliverables: Catalog and Presentation

Our main deliverables for our project were the creation of a comprehensive catalog and a concise powerpoint presentation. A key feature of both of these deliverables was a recommendation of which location and canopy design option our team discovered to be most feasible for the WPI community.

Our catalog was essentially a condensed version of our report, as it was made to give the reader an understanding of solar feasibility at WPI without requiring them to read our entire report. We provided background on renewable energy at WPI, specifically solar. On the next page, we highlighted the non-monetary benefits of solar panel canopies. We briefly covered the potential canopy designs and their specifications. The next 3 pages were our top options, beginning with the most feasible option, our recommendation. We then included other feasible options with specifications on payback period and information from our cost benefit analysis for each. We then included a table of all the lots that were analyzed, and provided evidence of why the others were not feasible. We outlined the potential funding options, as well as our own recommendation for financing the project. The catalog concluded with next steps that could be taken regarding outreach, planning, and implementation. We provided this information to the WPI Facilities department to be reviewed.

Our final PowerPoint presentation was similar to the catalog with regard to the information displayed. We presented it to the sustainability faculty and working groups at their planning meeting for the new sustainability plan on 23 April 2019 at 12:30. We began with an introduction of our project and stated our goal. We addressed the non monetary benefits of implementing a canopy on campus. We included pictures of each design option and elaborated on our recommendation and other feasible options for canopies. The funding options were presented in a table, with an emphasis on Power Purchase Agreements. Next steps were outlined not only for future project opportunities, but for possible planning and implementation.

Chapter 4: Results & Analysis

Following our data collection, common themes and values found through interviews and online research were combined with the results of our location analysis to create graphical representations of solar pathfinder and area data, to-scale AutoCAD sketches of our top parking areas, and in-depth analytical data tables in excel that estimate payback periods for our various options. First, the results of our location analysis are presented, relying on a number of graphs to better visualize the collected data. In this section, it is also explained why further analysis was narrowed down to 3 parking locations. Next, a number of decision and design matrices are presented to better compare these options to each other. The bulk of our numerical analysis is discussed in section 4.3, where the costs and benefits of each option are analyzed. Finally, a number of funding options obtained from our background research and interviews are discussed.

4.1 Location Analysis

In conducting our location analysis, we utilized a solar pathfinder to deduce the best potential locations for solar radiation exposure, measured total lot area with tape measure and GIS software, and took notes of other potential factors such as number of parking spaces and surrounding topography.

4.1.1 Solar Potential Utilizing Solar Pathfinder

During the initial analysis, our group took readings at centralized locations for each of the 12 lots on the WPI campus. As a result of using the pathfinder, we calculated the percent of total daily solar radiation for each month throughout the year as seen in Figure 18. It can be noted that during the winter months, roughly October through March, the percentage of radiation is somewhat lower for the majority of locations. The average annual radiation percentage ranges from 76.8% for the Einhorn Lot to 99.8% for the Gateway Garage.

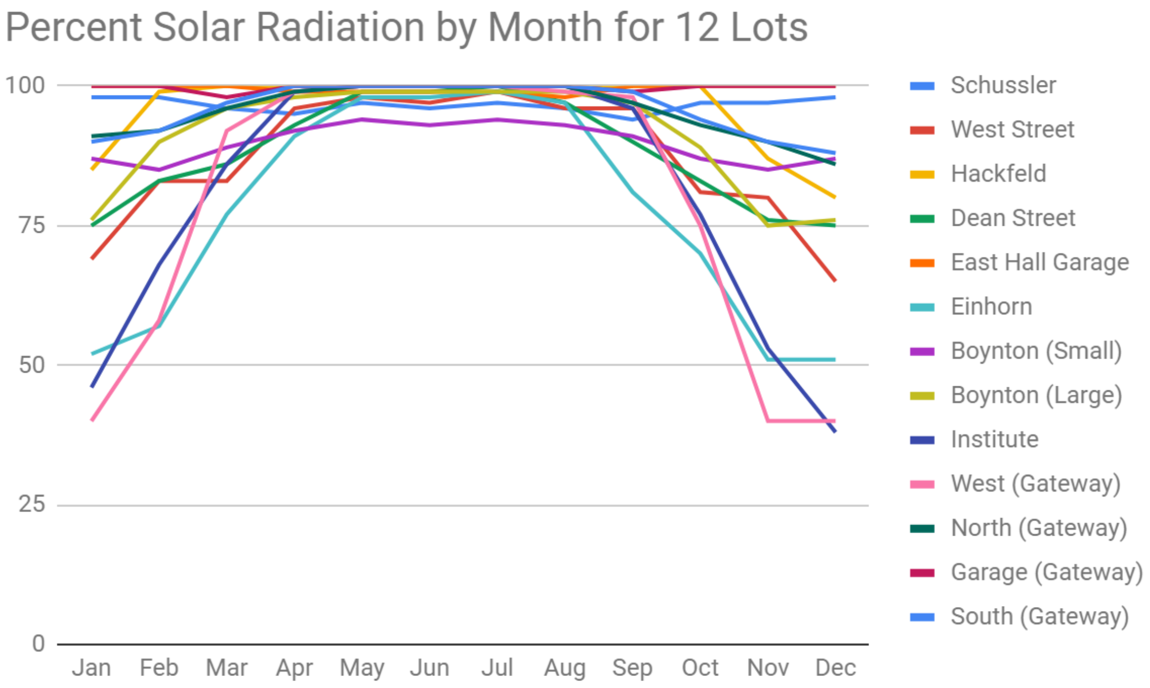


Figure 18 - Percent Solar Radiation by Month for all Potential Canopy Locations

The 3 lots with the greatest average annual solar radiation after the initial analysis were the North Lot (95.3%), the East Hall Garage (99.5%), and the Gateway Garage (99.8%).

Based on the initial readings, we then revisited these top 3 locations to perform a more in-depth analysis on solar radiation potential. Utilizing an additional 4 readings taken at the center of each quadrant of each of these locations, we were able to figure out a more concise solar radiation percentage to carry out our analyses. After compiling the 5 total readings for each lot, we then averaged their respective daily solar radiation percentage over the course of the year as shown in Figure 19.

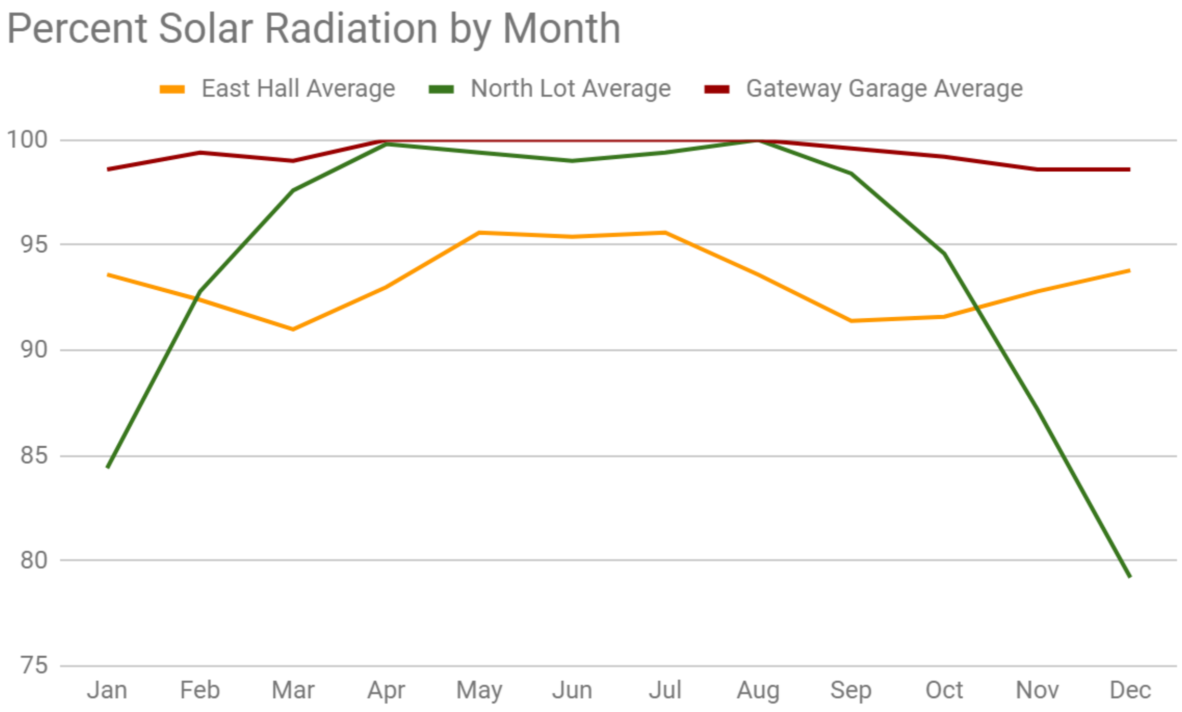


Figure 19 - Percent Solar Radiation by Month for the Top 3 Potential Canopy Locations

For the North Lot at Gateway, the readings had a significant dip at the 2 southernmost quadrants during the winter months because the Gateway Garage immediately borders it to the south. However, the overall average reading did not decrease much at all, ending up at 94.3 percent. The updated percentage with additional data points for the East Hall Garage had a much more significant drop in overall average, going from 99.5% down to 93.3%. The main reason for this is the East Hall building caused shade on the lower level of the garage's roof during the Spring and Fall. Seeing that this lot's reading had dropped lower than that of the North Lot, it would be a more difficult case to conclude as most feasible. The Gateway Garage saw little change in its overall solar radiation because there is almost nothing to cause any form of shade at the upper level apart from 2 antennas on the roofs of nearby buildings. The annual radiation percentage dropped ever so slightly from 99.8% to 99.4%. The importance of these readings is to provide a higher accuracy in our energy production calculations. The total amount of energy produced over the course of a year would be multiplied by these percentages to account for the time during hours of sunlight in which the sun does not hit the surface of the panels due to obstructions.

4.1.2 Lot Feasibility Based on Area

In addition to the solar potential, another part of our location analysis was to measure the specific area of each location to be able to understand the potential costs and energy production of a canopy system. Figure 20 provides the data for the total area measured in square feet for each lot on the WPI campus. The red bars are locations that we revisited in more depth.

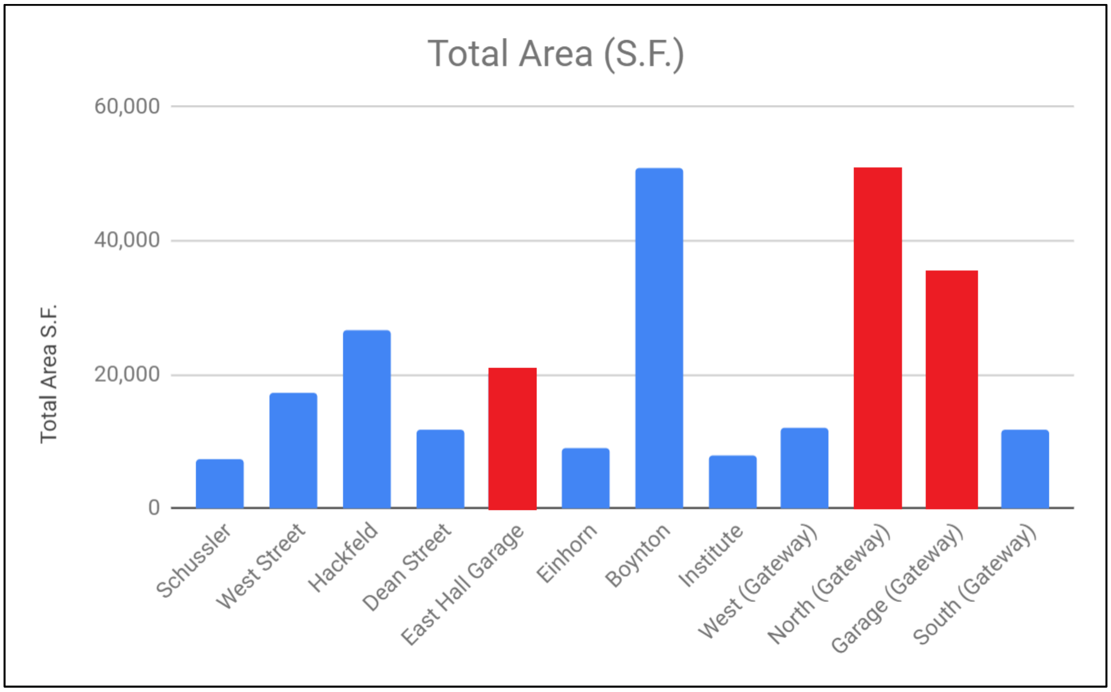


Figure 20 - Total Area of Potential Locations for a Solar Canopy on Campus

The top 3 lots for solar potential mentioned previously are also within the top 5 in terms of greatest area, which are 2 very important components in weighing feasibility. The larger the area in which a solar panel system is implemented, the more cost-effective it will be in the long run because it will be able to produce a higher amount of energy over the course of a year, information we had learned from our interview with Solect Energy (Solect Energy, 2019, March 28) (See Appendix F). Another reason for this is that the cost of energy increases about 3.5% each year (Energysage, 2019), so based on initial costs, the more energy a system produces will have an increasing value as the years progress, further decreasing the payback period. The North Lot at Gateway is the largest measured, being approximately 50,660 square feet, whereas both parking garages have a lower total surface area that can be utilized by a canopy system. The top of the Gateway Garage is slightly smaller, roughly 34,800 square feet, and the East Hall Garage measured at 20,160 square feet, which is less than half the size of the North Lot. A complete table showing the exact area of each lot analyzed can be found in Appendix B. These areas are essential information when calculating the possible energy produced by the different solar panel canopy types and how long it will take for each system to return on its investment.

4.1.3 Most Feasible Locations

After gathering data from a dozen parking areas across campus, we were able to narrow down our feasibility study to three locations - the East Hall Garage, Gateway Garage, and North Lot. These three parking areas had excellent solar radiation exposure, were all mostly flat surfaces, and placed in the top 5 in terms of area.

The other two large lots - Hackfeld and Boynton - were not further analyzed. Hackfeld Lot, although comparable to the East Hall Garage in size, was far less suitable as it is located on a fairly significant hill. Per conversations with Solect energy, solar canopies are almost always installed on flat ground as an incline would drastically raise construction costs and complicate the design - optimal panel orientation must be maintained in addition to proper clearance for vehicles (Solect Energy, 2019, March 28). In addition, there is a need to remove large trees along the central island of the parking lot, which would also increase costs. Boynton Lot, although just as large as the North Lot, was deemed infeasible for a solar canopy due to the pending construction of a new building in this location. The lot also ranked below our other top options in terms of annual solar radiation exposure, at about 90%.

The remaining 6 lots were not further analyzed due to their poor solar radiation exposure and their small size. These were the Einhorn, Schussler, Gateway West, Gateway South, Institute, and Dean Street lots. Per interviews with solar companies such as Solect Energy and Revision Energy, we learned that smaller lots are typically not as cost effective as larger options (Solect Energy, 2019, March 28); (Revision Energy Interview, 2019, April 10). This is because of the fact that the expensive canopy supports must still be installed, yet the surface area of the panels is smaller meaning less energy generation and a longer repayment period. Many of these lots also had poor sunlight exposure (again due to their small area), further diminishing their feasibility for a solar canopy.

As previously mentioned, the East Hall Garage, Gateway Garage, and North Lot are the three locations we deemed most feasible for a solar canopy. In addition to having the highest solar radiation exposure, they also placed in the top 5 in terms of area.

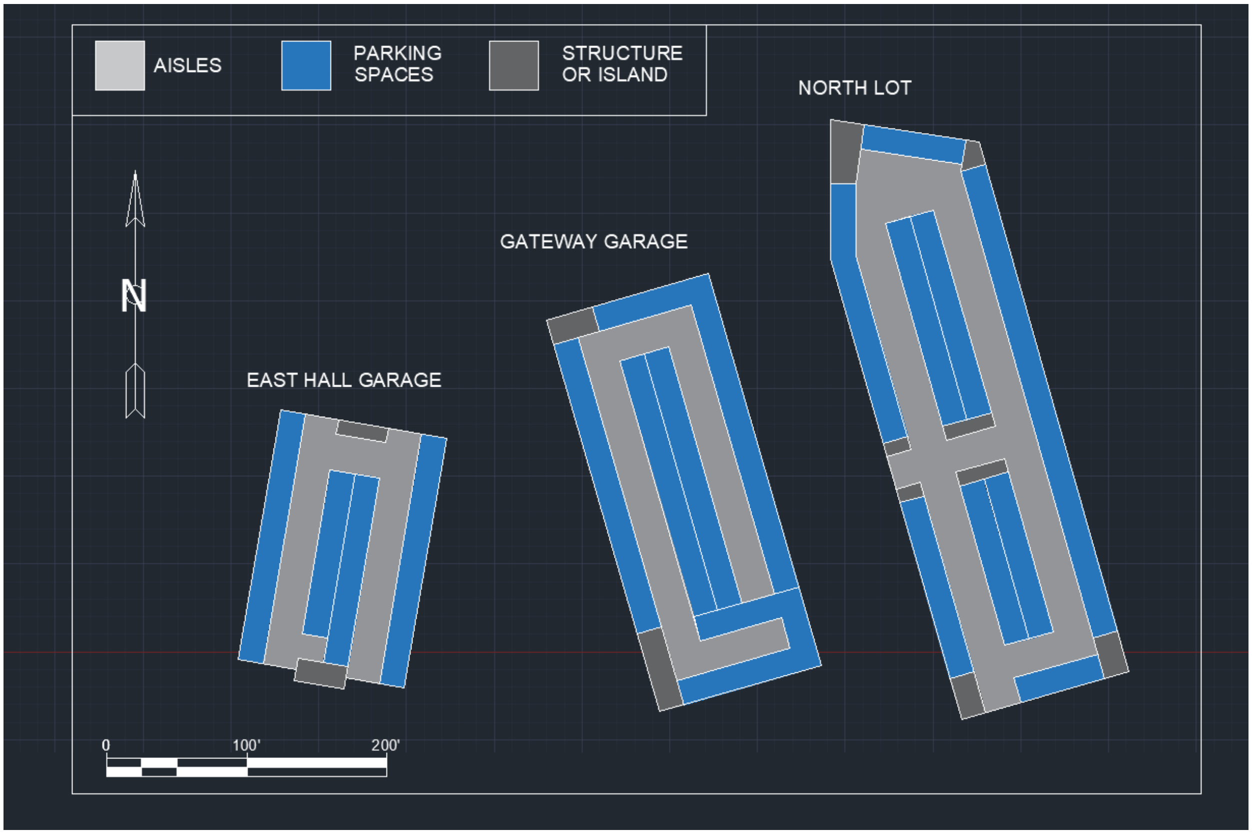


Figure 21 - Size Comparison of East Hall, Gateway, and North Lots

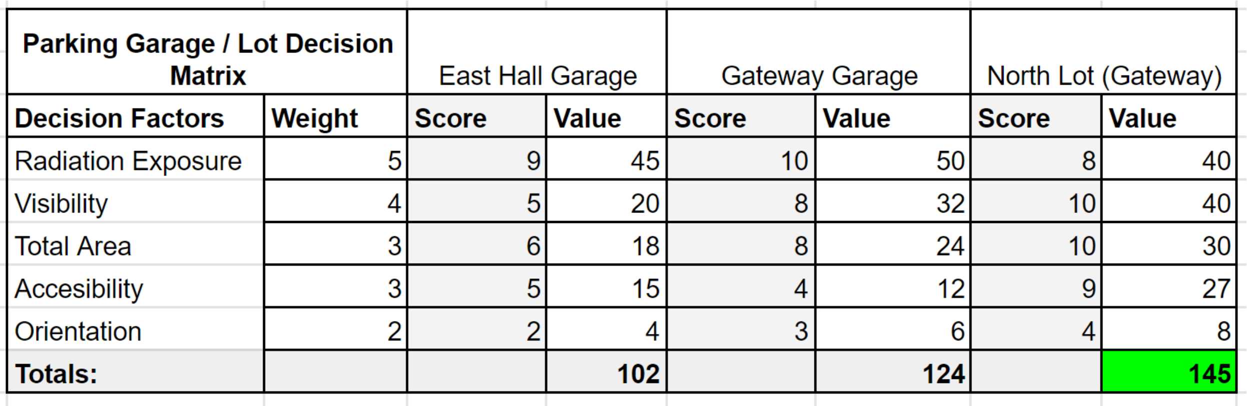
To help visualize the relative sizes of these areas to one another, we created 2D models using AutoCAD, shown in Figure 21. We also used this software to better mark the distinctions between aisles and parking spaces. Blue shading represents parking spaces, light gray shows aisles, while dark gray covers medians or stairwell structures on the garages.

4.2 Decision Matrices

After analyzing our results from our location analysis, we created a number of matrices to display this information in a more concise manner. These matrices also enabled us to compare and analyze our top options from a numerical point of view. We first created a decision matrix to rate the best parking area (section 4.2.1). We also created a decision matrix to choose the most feasible canopy support structure for the panels, discussed in section 4.2.2.

4.2.1 Parking Area Decision Matrix

A decision matrix for determining the most feasible location for a solar canopy out of the top rated options is shown in Figure 22. Based on this matrix, the North Lot at Gateway Park is the highest scoring option on a scale of 1 to 10.



Parking Garage / Lot Decision Matrix		East Hall Garage		Gateway Garage		North Lot (Gateway)	
Decision Factors	**Weight**	**Score**	**Value**	**Score**	**Value**	**Score**	**Value**
Radiation Exposure	5	9	45	10	50	8	40
Visibility	4	5	20	8	32	10	40
Total Area	3	6	18	8	24	10	30
Accesibility	3	5	15	4	12	9	27
Orientation	2	2	4	3	6	4	8
Totals:			**102**		**124**		**145**

Figure 22 - Decision Matrix for Choosing a Parking Area

Radiation Exposure - Radiation exposure refers to the total annual solar radiation exposure the parking area receives - further information can be found in 4.1. This factor was deemed most important with a weight of 5 because an area's exposure to the sun will have a direct effect on its energy production, which in turn will affect its revenue and payback period. All three locations had high ratings in this area, however the Gateway Garage had the most sunlight exposure at 99.4%.

Visibility - Visibility refers to the visibility of the solar panels to campus visitors or the general public. Although this factor does not affect cost or energy production, we nevertheless found it important as it advertises WPI's use of sustainable practices. The North Lot and Gateway Garage are highly visible from the Interstate 290 highway, while East Hall is comparatively secluded. Gateway Garage may be slightly less visible as only the underside of the panels would be visible to passerby - they may think it is some other sort of roofing structure and not solar panels.

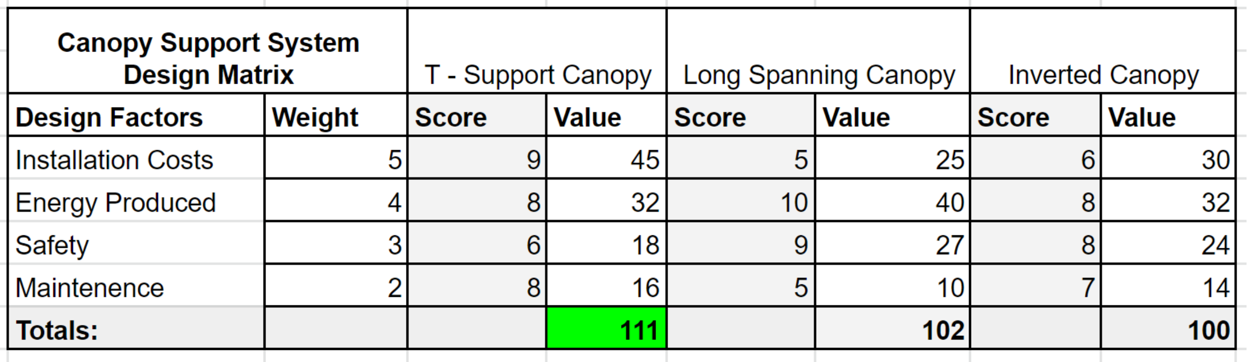
Total Area - Total area is defined as the total square footage of the parking lot of garage roof. This was rated as moderately important as per interviews with installation companies, a larger surface area for a solar canopy is generally more economically feasible - the system will cost more, but will generate more energy (and savings) over time. The North Lot is the largest of the three at 50,660 square feet, Gateway second at 34,800 and East Hall coming in at half the size of North at around 20,160.

Accessibility - Accessibility refers to the ease of accessing the site as far as initial construction and future maintenance are concerned. The North Lot scored highest in this category, as it is located in a flat area only a few hundred feet from a major highway exit / entrance - enabling materials to be transported and stored on site more easily. In comparison, the Gateway Garage and the East Hall Garage received lower scores since construction would take place on the 5th and 3rd floors respectively. This would require a crane, and overall further complicate construction in terms of both logistics and overall cost.

Orientation - Orientation refers to the direction in which the panels could be tilted. Due south (180 degrees) is the most effective in terms of energy production. The long axis of all three lots is in the north - south direction, meaning the panels would likely be tilted slightly in the east - west direction. All three lots were given low scores in this category. The North Lot had more south facing rows of spaces than Gateway Garage, and the both were slightly more south facing than East Hall.

4.2.2 Canopy Type Decision Matrix

In addition, a decision matrix for determining the best canopy support structure is shown in Figure 23. This matrix shows the T Support canopy as having the highest score on a scale of 1 to 10, followed by the long spanning and then inverted styles.



Canopy Support System Design Matrix		T - Support Canopy		Long Spanning Canopy		Inverted Canopy	
Design Factors	**Weight**	**Score**	**Value**	**Score**	**Value**	**Score**	**Value**
Installation Costs	5	9	45	5	25	6	30
Energy Produced	4	8	32	10	40	8	32
Safety	3	6	18	9	27	8	24
Maintenence	2	8	16	5	10	7	14
Totals:			**111**		**102**		**100**

Figure 23 - Decision Matrix for Choosing a Canopy Support System

Installation Costs - Based on conversations with Ms. Elizabeth Tomaszewski and Dr. Paul Mathisen, The Associative Director of Sustainability and The Director of Sustainability at WPI respectively, installation costs of the system were deemed most important, as the price tag of the system will be of high interest to the WPI administration (Tomaszewski, 2019, April 12). Detailed analysis of these costs can be found in section 4.4; however to summarize here, the T Support is least expensive to install. The inverted design is more expensive per unit area, however the long spanning ranks lowest as it is the most expensive in total cost.

Energy Produced - Energy production was also deemed highly important, as it is the main intended purpose of the solar system. In addition, the energy production also contributes to the duration of the repayment period and future savings for the school. The long spanning design scores a 10 as it produces notably more energy than the T Support and inverted designs, which are nearly identical.

Safety - The main safety factor with solar canopies is falling snow. This is most dangerous with T Support canopies, as the design only covers parking spaces - meaning snow can fall in aisles. The inverted design has similar coverage but collects snow in the bottom of its “v” shape making it safer. Since the long spanning design covers the entire parking lot, snow only falls on the edges of the lot.

Maintenance - Maintenance refers to the ease of access to the canopy surface to conduct routine checkups and remove snow. This category was rated with low importance as these check-ups would be done by the installation company - WPI Facilities would likely only be involved with clearing snow or other debris. The T Support ranks highest as most snow will clear itself due to its angled surface. Snow will need to be removed from the central trough of the inverted design, and will need extensive attention on the flat long spanning system (Solect Energy, 2019, March 28); (Revision Energy Interview, 2019, April 10).

4.3 Cost / Benefit Analysis

Our cost benefit analysis was the culmination of much of our background research, installer and college interviews, and location analysis. A significant portion of this analysis came in the form of excel data sheets that sought to estimate energy generation and payback periods for different options over time. This information was sourced largely from online databases and installer interviews. Other non-monetary costs and benefits were also considered, discussed in sections 4.3.2 and 4.3.3 respectively.

4.3.1 Cost Analysis & Payback Period

Starting with a T Support canopy design in the North Lot, the entire area of the lot is made up of 136 parking spaces, which results in an approximate total power of 816 kilowatts (kW) for this specific canopy type. This is based on the estimator from Solect Energy showing that the power of such a canopy system using Tier 1, 350 watt panels would consist of roughly 6 kW per standard parking space which is 9x18 square feet (Solect Energy, 2019, March 28). As for the cost of such a system, the T Support design would cost $3.50 per watt to own, totaling approximately $2,427,600 net cost for the complete array of panels including the deducted SMART and MACRS incentive benefits. These numbers provided for total power and total cost were further confirmed by Revision Energy to achieve a higher level of accuracy (Revision Energy Interview, 2019, April 10). Through utilization of the NREL calculator and factoring in the average daily solar radiation of the lot, the annual energy production of an 816 kW T Support system would generate 894,671 kilowatt-hours (kWh) of energy, which would result in a value of $169,451 based on the current cost of commercial energy in Worcester is 18.94 cents per kWh (National Renewable Energy Laboratory, 2019). However, this cost is expected to grow about 3.5% each year which was accounted for in our payback analysis. After factoring in the yearly increase in energy cost coupled with the degradation of the panels and incentives, a T Support canopy system in the North Lot would have a payback period of roughly 7.75 years, and at the end of the 20-year incentive period, it would accumulate a profit of $4,685,500. To better visualize our results, we have created the following tables for each lot, encompassing the values for each canopy type respectively.

Table 2 - North Lot Canopy Support Options

136 Parking Spaces	T Support	Long-Spanning	Inverted
System Size (kW)	816	1570	816
Cost per Watt ($)	$3.50	$3.25	$3.75
Total Cost ($) (with SMART & MACRS)	$2,427,600	$4,337,100	$2,601,000
First-Year Energy Generation (kWh)	894,671	1,680,059	881,460
Value of First-Year Generated Energy ($)	$169,451	$318,203	$166,949
Payback Period (Yrs)	7.75	7.5	8.5
20 Year Savings ($)	$4,685,500	$9,020,200	$4,407,000

Table 3 - Gateway Garage Canopy Support Options

92 Parking Spaces	T Support	Long-Spanning	Inverted
System Size (kW)	552	1289	552
Cost per Watt ($)	$3.50	$3.25	$3.75
Total Cost ($) (with SMART & MACRS)	$1,642,200	$3,560,900	$1,759,500
First-Year Energy Generation (kWh)	637,950	1,453,960	628,532
Value of First-Year Generated Energy ($)	$120,828	$275,380	$119,044
Payback Period (Yrs)	7.5	7	8
20 Year Savings ($)	$3,429,800	$7,998,800	$3,237,635

Table 4 - East Hall Garage Canopy Support Options

67 Parking Spaces	T Support	Long-Spanning	Inverted
System Size (kW)	402	747	402
Cost per Watt ($)	$3.50	$3.25	$3.75
Total Cost ($) (with SMART and MACRS)	$1,196,000	$2,063,600	$1,281,400
First-Year Energy Generation (kWh)	431,658	790,888	421,795
Value of First-Year Generated Energy ($)	$81,756	$149,794	$79,888
Payback Period (Yrs)	7.5	7.25	8.25
20 Year Savings ($)	$2,235,900	$4,224,400	$2,072,100

4.3.2 Non-Included Costs

While there are multiple ways to fund a solar panel canopy, some associated costs are not included in the upfront price. For example, any lighting and security cameras would need to be relocated. This would include not only paying for the current ones to be removed, but for the newer ones to be installed. Certain related infrastructure requirements may also not be accounted for, such as network cables. During construction, there may also be need for police details to monitor and assist with nearby traffic. Finding additional parking during the construction phase may also pose a problem, due to WPI's existing lack of available parking. If the North Lot was to be under construction for upwards of 4 to 6 months, WPI might have to look into renting an additional lot to accomodate for the temporary loss of space (Gagne, 2019 April 09).

4.3.3 Non-monetary Benefits

The non-monetary benefits associated with solar panel canopies are numerous:

Table 5 - Non-monetary Benefits

Application	Benefits & Examples
Solar energy (	- Reduces impact of climate change - Reduces reliance on nonrenewable energy sources - Decreases reliance on grid - Canopies are well-suited for urban environments, space efficient
Visibility	- Promotes image of sustainability - Increases interest within the sustainability department
Alternative uses	- Electric Vehicle charging stations - Water conservation
Education	- Opportunities for research and study - IQPs & MQPs - Appeals to prospective students interested in sustainability
Parking Areas	- Reduces need to plow - Decreases re-paving frequency of the lot - Protects vehicles and pedestrians

*Data from (Solect Energy (2019, March 28); (Casey & Cardoso, 2018, October 08); (Mathisen, 2019, April 09); (Tomaszewski, 2019, April 12); (Gagne, 2019, April 09); (Revision Energy Interview, 2019, April 10)

4.4 Potential Funding Options

There are a number of potential funding options for a solar canopy system at WPI. Many federal or state incentive programs are available to reduce the overall cost of a solar canopy system. The general purpose and functionality of these programs has been discussed in background section 2.4. The relevance of these programs specific to a solar canopy at WPI is discussed below, along with other potential sources of funding. Much of this information was gathered from interviews with solar installation companies or from our talks with Stonehill College (Gagne, 2019 April 09).

The first option for funding a solar canopy is direct ownership. In this case, WPI buys the system outright - however, it can benefit from a variety of significant incentives to cut costs or increase savings. Specifics for where WPI could source the remainder of these funds are described in sections 4.4.1 and 4.4.2. The second option is a solar lease, in which a third party builds and pays for the system. WPI then rents the system from the third party, similar to any other lease. The third option is a Power Purchase Agreement (PPA), which is very similar to a lease except for the fact that WPI buys the energy per kWh instead of renting the entire system. This may be more practical if WPI only wants to use a certain percentage of the energy generated. Both leasing and PPA's minimize the upfront cost, however could increase costs in the long term depending on the specifics of the contract agreement as WPI will continually be paying for either rent or energy (Gagne, 2019 April 09). Stonehill College chose to use a PPA to pay for their system, as they did not have the funds to pay for direct ownership. These options are compared more directly in Table 5.

Table 6 - Funding Options for a Solar Canopy System at WPI

Ownership	**Ownership with Partner**	**PPA**
WPI pays **~$2,427,600** net cost WPI Qualifies for… **SMART** $0.14 / KwH for 20 years **MACRS** pays 15% of installation cost **$4,700,000** estimated savings over 20 years Estimated payback **7 - 8 year** WPI fully owns system, and deals with all potential benefits and risks on its own	WPI & Partner pay **~ $1,400,800** net cost WPI & Partner Qualify for... **Federal ITC** pays 30% of installation cost via tax credit **SMART** $0.14 / kWh for 20 years **MACRS** pays 15% of installation cost **$2,800,000-$3,200,000** estimated savings over 20 years Estimated payback **5 - 6 years** Many fine details are a largely gray area and would be worked out in a specific contract agreement	Third party pays **~$1,400,800** net cost Partner Qualifies for... **Federal ITC** pays 30% of installation cost via tax credit **SMART** $0.14 / kWh for 20 years **MACRS** pays 15% of installation cost **$1,350,000-$2,600,000** estimated savings over 20 years Payback not applicable as WPI has no upfront cost WPI buys back energy from the system at reduced rates. Typically system is turned over after 20 years of third party ownership

*Leasing options and PPAs vary greatly by solar installer and specific contract agreements

If WPI were to pursue direct ownership of the solar canopy system, there are further options as to where the money to pay for the installation costs would be sourced from. These options are discussed at detail in the following subsections.

4.4.1 Bonds

For the remaining costs, there are a number of options for WPI. The first option is to take out a bond - a common option for private universities. WPI has historically taken bonds from the Massachusetts Development Finance Agency (MDFA). In 2017, the university took $49 million from the MDFA in a tax exempt revenue bond series and $57 million in University taxable bonds (Worcester Polytechnic Institute, 2017, June 30). Some of these bonds were used for typical tasks such as advancing previous bonds or paying costs of issuance, however nearly half of these bonds were used for a new campus construction project - the $49 million Foisie Innovation Studio (Worcester Polytechnic Institute, 2017, June 30). Although these numbers may seem large, WPI is a financially conservative institution (Tomaszewski, 2019, April 12). This means that minimizing upfront costs and shortening the payback period are top priorities. Although the canopy system would eventually pay for itself from its electricity generation, WPI may seek to speed up this repayment period by increasing tuition costs, or making budget cuts in other areas.

4.4.2 Donations

In addition to a typical bond, other options for payment include gifts. Senior class gifts at WPI date back to 1910, and are comprised of donations from senior class members to the university. Currently, there are numerous incentives for the class of 2019 to donate - drawstring bags, a glass pint, and alumni membership or conference invitations are given based on the donation amount (Worcester Polytechnic Institute, 2019). Historically, a trustee has also matched the donation amount of the student body, doubling the size of the gift. Although these gifts likely would not cover the total cost of the canopy system, it would still lower the cost to the school itself. This would also serve to further involve the WPI student community in renewable energy practices, and mark a great example of student devotion to sustainability.

A final funding option for an on campus canopy system may come in the form of alumni or other donations. Similarly to a class gift, this funding would serve to lower the financial burden of a solar canopy system to WPI, or even erase it entirely. Over the years, WPI has received millions in donations from its alumni, with the largest donor being Robert Foisie, who donated $63 million over his lifetime (Worcester Polytechnic Institute, 2019). In our informal interview with Mr. James Dunn, we discussed how a properly advertised program could draw the attention (and donations) of numerous WPI alumni with an interest in renewable energy or a general interest in bettering their college. Interested donors could also give a gift to WPI with the restriction of their gift being used to construct a solar canopy. Overall, there are a variety of effective funding options for a canopy system, many of which involve the student and alumni communities.

Chapter 5: Recommendations

Our solar panel canopy cost/benefit analysis for WPI provided us with the knowledge to make recommendations for the most feasible options regarding location, design, and financing. Our specific recommendations were supplemented with the next steps that should be taken by WPI for actual implementation of a solar canopy system. The potential role of solar panel canopies in the new WPI Sustainability Plan was also explored. Our main deliverables for the project were the creation of a catalog that displayed various design and funding options for a solar panel canopy system at WPI, as well as giving key background information about solar canopies and renewable energy at WPI. We also delivered a concise 5 minute PowerPoint presentation at the Sustainability Plan Community Update held on 23 April 2019.

5.1 Location and Canopy Option

Our recommendation for a solar canopy system at WPI is a T Support system installed at the North Lot located at Gateway Park shown in Figure 24. This recommendation is based on our cost benefit analysis, which is in turn based on background research and information gathered from interviews (see Appendix F). This is WPI’s largest parking area at over 50,000 square feet, and also has excellent solar radiation exposure at 94.3%. In addition, the parking lot is highly visible from the heavily trafficked Interstate 290, which would advertise WPI’s renewable practices to the broader Worcester community. This would also ease construction costs, as the parking area is located close to a major highway exit meaning construction vehicles and materials will have easy access to the job site.

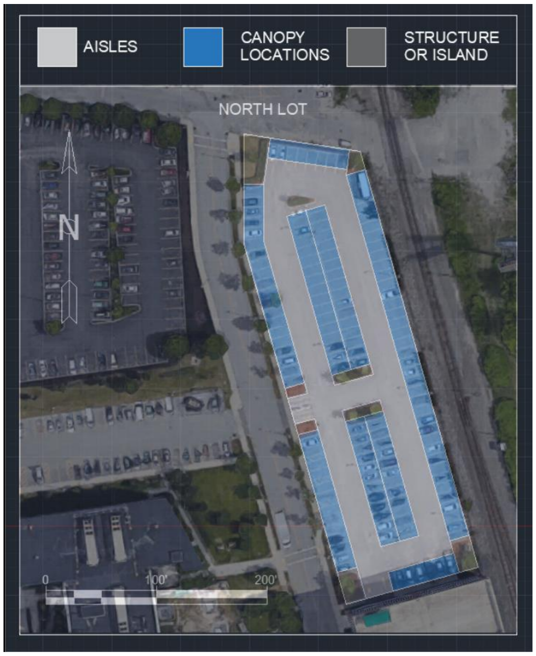


Figure 24 - North Lot with proposed T Support Canopy System

The T Support Canopy option was deemed most feasible for WPI, mostly due to its low relative cost. The $2.4 million capital cost and 7.75 year repayment period provided in section 4.3.1 take into account both the SMART and MACRS incentive benefits, but not ITC benefits which would require WPI to partner with a for-profit. Furthermore, after the standard 20 Year period in which these incentives last, WPI is expected to save $4.7 million in energy costs if they owned the system. This recommendation has resulted from the culmination of our finalized cost benefit analysis and comparing it to every other location and canopy type respectively. Further information can be found in our catalog, shown in Appendix E.

5.2 Financing Options

While there are a number of potential financing options for a solar canopy system, a Power Purchase Agreement (PPA) is our recommended option for WPI, as this would minimize upfront costs to the school while still providing about $1.3 to $2.6 million in savings over 20 years (see Appendix D). Despite the benefits of ownership ($4.7 million in savings), a PPA is likely a more attractive option to WPI due to the minimal upfront cost. These savings are from the reduced cost of buying electricity from the solar installer rather than the utility (National Grid) - however specific savings and other details would be ironed out during the contract agreement. The previously mentioned $2.4 million estimated net cost of the system would be handled by the third party installer, whereas WPI would only need to fund minor costs such as parking rearrangements or police details. This funding option is fairly common for nonprofits such as colleges due to the minimal upfront cost. Stonehill College also chose this purchasing option for their solar canopy system, as well as their other large scale solar projects. Typically, the solar installer owns the system for 20 years before handing it over to the college. Despite not directly owning the system for its first 20 years of use, WPI will still be able to benefit from the other non-monetary benefits discussed in section 4.4.3 (Gagne, 2019 April 09).

5.3 Implementation and Next Steps

Should the WPI Administration and Facilities Department decide to further pursue implementing a solar panel canopy, there are additional practical steps that should be taken into consideration. We recommend that the majority of this planning take place before and during construction. First, WPI should seek to get quotes from solar panel companies. We would refer WPI to inquire about canopies from both Solect Energy and ReVision Energy based on both company's experience with similar projects. Seeking information from multiple companies beyond the two aforementioned will help WPI to obtain the least expensive quote to own or best rate on a power purchase agreement. These companies will also be able to provide more detailed information regarding the expected construction timeline (Gagne, 2019 April 09). We would also recommend WPI use an expert tax consultant to ensure that WPI is maximizing the available benefits to lower costs. Because WPI as a nonprofit does not qualify for all incentives, it is important to include the opinion of a knowledgeable professional (Gagne, 2019 April 09).

Other planning might need to be factored in for related elements, such as the number of charging stations WPI would need to install for electric vehicles to accommodate for the current demand (Tomaszewski, 2019, April 12). Likewise, adding the water collection feature would also need to be planned in advance. Devising a plan for the usage of chargers or applications for the rainwater collected should be created in advance. Similarly, WPI would need to create a temporary plan for parking during the construction period (Gagne, 2019 April 09). Parking is already an issue at WPI, and closing off the largest lot for an estimated period of 4-6 months would not support the amount of vehicles (Solect Energy, 2019, March 28); (Revision Energy Interview, 2019, April 10). One possible solution involves opening up the Gateway Garage to those who typically park in the North Lot. Based on our observations, the top 3-4 floors were empty every time the area was inspected. Finally a plan for outreach and engaging the community would help to promote the WPI Office of Sustainability (Mathisen, 2019, April 09).This could include holding an event open to the public to educate and celebrate renewable energy. The solar canopies could also be utilized for research, whether it be at WPI or other local institutions. At WPI, the project could be applicable to future IQPs, MQPs, or additional research. Also having a plan to showcase it to prospective students could be helpful in gaining interest, not only in the school, but in sustainability at WPI (Tomaszewski, 2019, April 12). While most of the planning has been done as far as which solar panel canopy would be the most feasible for WPI, addressing implications of the project would need to be defined.

5.4 Solar Panel Canopies in the New Sustainability Plan

Attending the Sustainability Plan Community Update allowed us to consider how a solar panel canopy might help to meet new objectives regarding WPI's sustainability. The areas of sustainability our project was most associated with included: Facilities and operations, community engagement, and research. A solar panel canopy would help to meet many of the objectives outlined by the Facilities and operations component, such as the reduction of carbon emissions, achievement of net zero energy in buildings, and increase of renewable energy usage on campus. A canopy could also positively contribute to community engagement by contributing to student interest and knowledge of sustainable practices. Our recommendation for a canopy in the North Lot would also be highly visible to the community. Implementing this project could also assist with increasing research opportunities available and could promote more classes based in sustainable initiatives, possibly for renewable energy in urban environments.

Attending the event also provided us with further contacts and prompted interest in our project. Our catalog was viewed by much of the Office of Sustainability including Mr. Eric Beattie, the Vice President for Campus Planning and Facilities Management. Through various discussions with attendees, we observed there was interest for expanding renewable energy use on campus, potentially through a solar canopy. Differing opinions regarding our selected most feasible option (North Lot) were given, with some suggesting the parking garages could be more feasible. We also discovered our project could be a candidate for the Green Revolving Fund. Overall our presentation was well-received, and further interest in our catalog was expressed.

Chapter 6: Conclusion

Our Project, Envisioning Solar Panel Canopy Systems at WPI, assessed the feasibility of WPI's various parking areas for a solar canopy system, and developed a recommendation for the most effective option, supported with an in-depth cost/benefit analysis.

Before undertaking our data collection, we determined the necessary background information for our audience to know and we detailed the elements that would be involved in such a study. First, we included a comprehensive overview of why renewable energy is important and its role at WPI, specifically the role of solar energy. We elaborated on potential applicable incentives for solar energy such as tax credits and deductions, and the SMART and MACRS programs. Research of different systems for solar energy and types of panels was critical to be aware of prior to our assessment of a canopy option. Next, we addressed the different possibilities for canopy designs, for example T Support, longspanning, or inverted. We added a chapter on additional considerations such as safety, warranties, and other applications like charging stations for electric vehicles. These considerations were important for determining insurance and potential lifetime of the system. Case studies for how a typical feasibility study for a canopy system would be implemented was also researched to ensure our assessment was accurate. Elements including surveying the site, running a cost/benefit analysis, and determining the average payback period were all explored in our own study. Other colleges, such as Stonehill, who rely on solar energy or have a canopy system in place, served as models for how WPI could go about installing such a project.

Our methods chapter relied on our background knowledge and we began by developing an understanding of the current sustainability organizational structure. This allowed us to define key stakeholders for later interviews and discussions. We further explored how the canopy would be included with local initiatives and incentives. Interviews were a main component of our methodology. Best protocols were followed and we conducted both formal and informal interviews. Informal interviews were conducted with an expert in solar energy, The Director of Sustainability at WPI, and the Associative Director of Sustainability at WPI. Formal interviews were held with two installers of solar panel canopies and The Director of Sustainability at Stonehill College. Specifics for maintenance and installation costs, cost versus benefits, and return on investment calculations were studied. Lastly, we described our deliverables and how they have furthered our assertions.

A combined results and analysis chapter allowed us to complete an in depth evaluation that lead into our recommendations chapter. Our location analysis reported on the data collected from the solar pathfinder and measured area. These results provided the basis for our determination of the 3 best lots or garages to be further analyzed: The North Lot, The Gateway Garage, and The East Hall Garage. Two decision matrices, one for the lot or garage and another for canopy type, allowed us to standardize our investigation into the best or most feasible location. While we asserted that North Lot and T Support design would be the best combination, we continued our analysis for the three best lot options so we could provide additional recommendations. Our cost/benefit analysis was a critical component in assessing feasibility and examined payback periods, non-included costs, and non-monetary benefits. Finally, we reported the various funding options available and how each would impact affordability for WPI. Options involved: ownership (possibly supplemented with bonds and donations), ownership with a partner, and power purchase agreements.

Our background, methodology, and results and analysis chapters culminated in recommendations concerning canopy design and location, financing, and next steps. Our recommendations also included how such a project could be incorporated into the new sustainability plan or utilized for future IQPs or MQPs. We concluded, based on our cost benefit analysis, that the most feasible option was a T-support canopy in the North Lot funded by a power purchase agreement.

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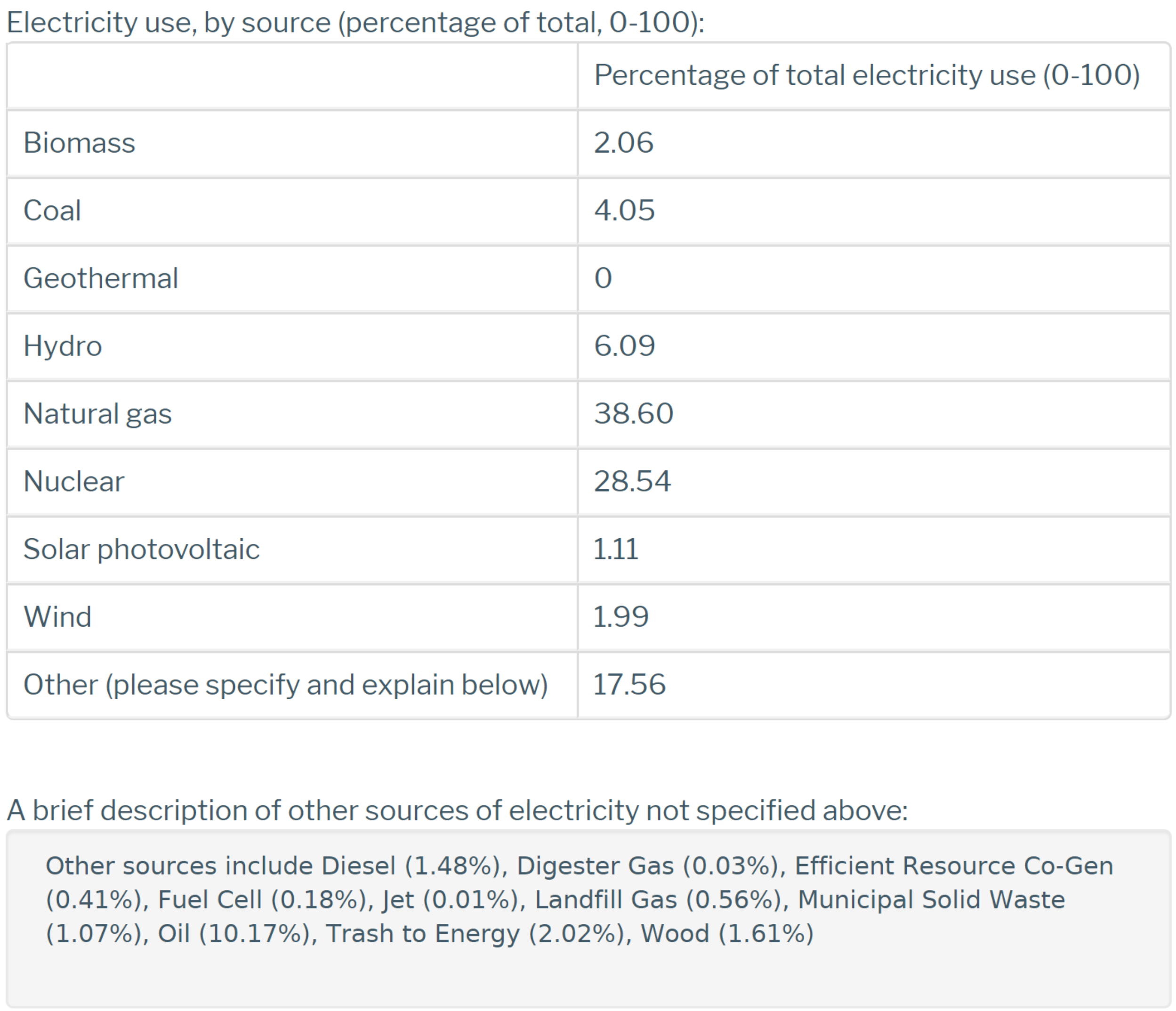
Appendices

Graphs, tables, statistics, questions, and other miscellaneous data collected from research, interviews, and on the field is organized below in various appendices.

Appendix A: WPI Electricity Generation by Source



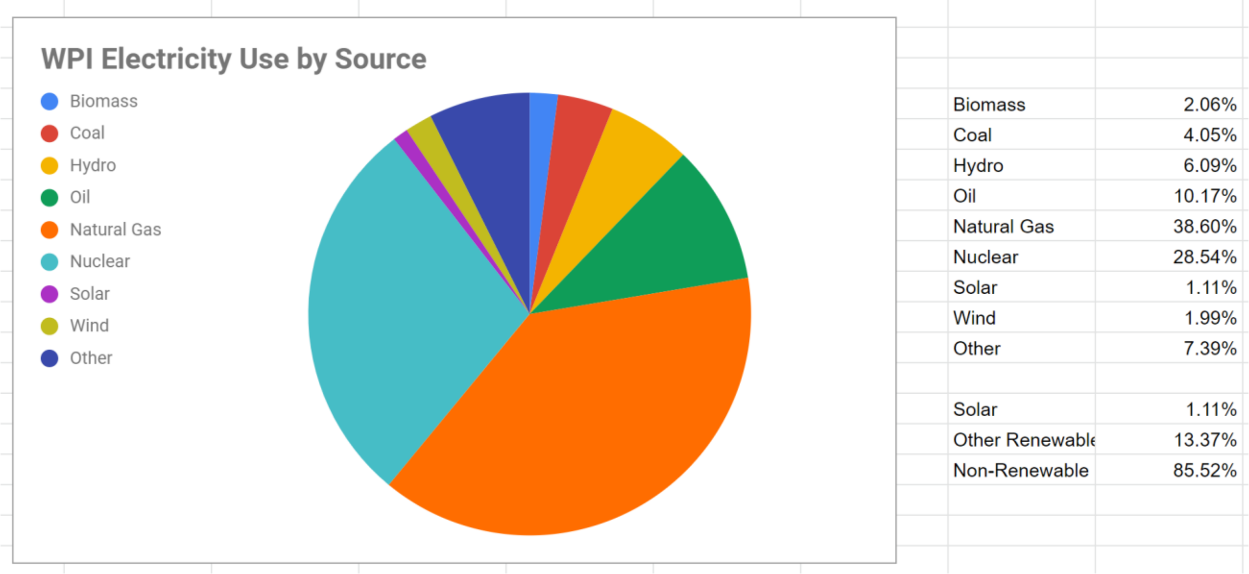
Electricity use, by source (percentage of total, 0-100):

	Percentage of total electricity use (0-100)
Biomass	2.06
Coal	4.05
Geothermal	0
Hydro	6.09
Natural gas	38.60
Nuclear	28.54
Solar photovoltaic	1.11
Wind	1.99
Other (please specify and explain below)	17.56

A brief description of other sources of electricity not specified above:

Other sources include Diesel (1.48%), Digester Gas (0.03%), Efficient Resource Co-Gen (0.41%), Fuel Cell (0.18%), Jet (0.01%), Landfill Gas (0.56%), Municipal Solid Waste (1.07%), Oil (10.17%), Trash to Energy (2.02%), Wood (1.61%)

Figure A1 - WPI Electricity Generation by Source (Worcester Polytechnic Institute OP-6: Clean and Renewable Energy, n.d.)



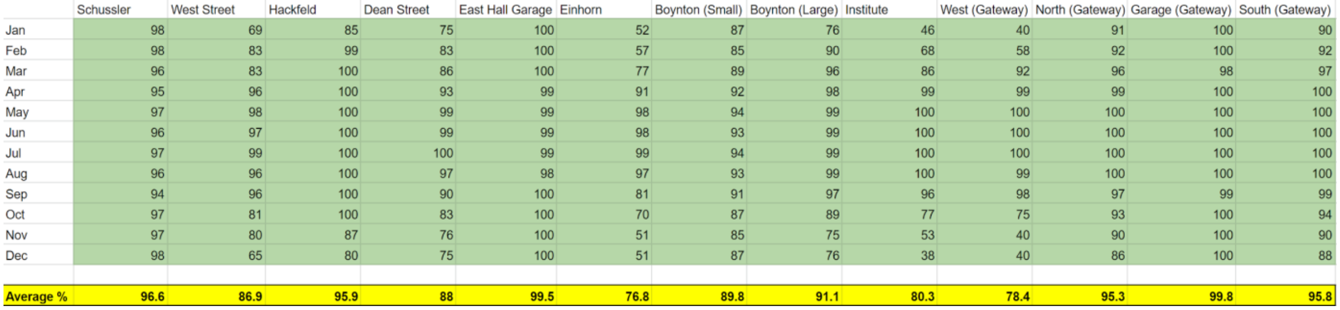
Biomass	2.06%
Coal	4.05%
Hydro	6.09%
Oil	10.17%
Natural Gas	38.60%
Nuclear	28.54%
Solar	1.11%
Wind	1.99%
Other	7.39%
Solar	1.11%
Other Renewabl	13.37%
Non-Renewable	85.52%

Figure A2 - WPI Electricity Use by Source Pie Chart

Appendix B: Location Analysis Information

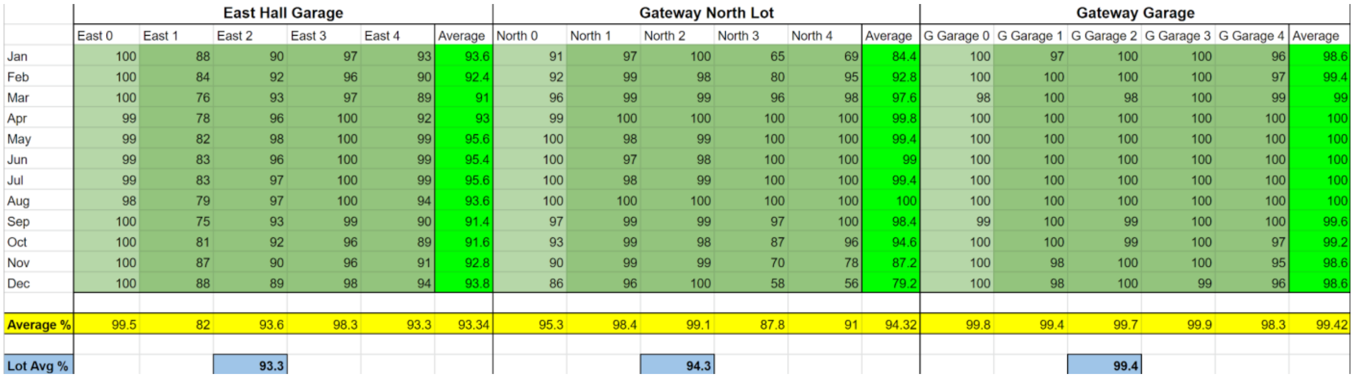
Table B1 - Surface Areas of WPI Parking Areas

Lot Name	GIS Measured TOTAL Area (Square Feet)	Tape Measured TOTAL Area (Square Feet)
North Lot (Gateway)	50,660	44,200
Boynton Lot	50,400	50,992
Gateway Garage	34,800	34,800
Hackfeld Lot	27,500	26,538
East Hall Garage	21,600	20,160
West Street Lot	14,925	17,405
West Lot (Gateway)	12,000	12,000
South Lot (Gateway)	14,400	11,656
Dean Street Lot	14,000	11,632
Einhorn Lot	8,250	8,880
Institute Lot	7,200	7,800
Schussler Lot	7,500	7,375



	Schussler	West Street	Hackfeld	Dean Street	East Hall Garage	Einhorn	Boynton (Small)	Boynton (Large)	Institute	West (Gateway)	North (Gateway)	Garage (Gateway)	South (Gateway)
Jan	98	69	85	75	100	52	87	76	46	40	91	100	90
Feb	98	83	99	83	100	57	85	90	68	58	92	100	92
Mar	96	83	100	86	100	77	89	96	86	92	96	98	97
Apr	95	96	100	93	99	91	92	98	99	99	99	100	100
May	97	98	100	99	99	98	94	99	100	100	100	100	100
Jun	96	97	100	99	99	98	93	99	100	100	100	100	100
Jul	97	99	100	100	99	99	94	99	100	100	100	100	100
Aug	96	96	100	97	98	97	93	99	100	99	100	100	100
Sep	94	96	100	90	100	81	91	97	96	98	97	99	99
Oct	97	81	100	83	100	70	87	89	77	75	93	100	94
Nov	97	80	87	76	100	51	85	75	53	40	90	100	90
Dec	98	65	80	75	100	51	87	76	38	40	86	100	88
Average %	**96.6**	**86.9**	**95.9**	**88**	**99.5**	**76.8**	**89.8**	**91.1**	**80.3**	**78.4**	**95.3**	**99.8**	**95.8**

Figure B1 - Solar Radiation Exposure Percentages for 12 Parking Areas



	East Hall Garage						**Gateway North Lot**						**Gateway Garage**					
	East 0	East 1	East 2	East 3	East 4	Average	North 0	North 1	North 2	North 3	North 4	Average	G Garage 0	G Garage 1	G Garage 2	G Garage 3	G Garage 4	Average
Jan	100	88	90	97	93	93.6	91	97	100	65	69	84.4	100	97	100	100	96	98.6
Feb	100	84	92	96	90	92.4	92	99	98	80	95	92.8	100	100	100	100	97	99.4
Mar	100	76	93	97	89	91	96	99	99	96	98	97.6	98	100	98	100	99	99
Apr	99	78	96	100	92	93	99	100	100	100	100	99.8	100	100	100	100	100	100
May	99	82	98	100	99	95.6	100	98	99	100	100	99.4	100	100	100	100	100	100
Jun	99	83	96	100	99	95.4	100	97	98	100	100	99	100	100	100	100	100	100
Jul	99	83	97	100	99	95.6	100	98	99	100	100	99.4	100	100	100	100	100	100
Aug	98	79	97	100	94	93.6	100	100	100	100	100	100	100	100	100	100	100	100
Sep	100	75	93	99	90	91.4	97	99	99	97	100	98.4	99	100	99	100	100	99.6
Oct	100	81	92	96	89	91.6	93	99	98	87	96	94.6	100	100	99	100	97	99.2
Nov	100	87	90	96	91	92.8	90	99	99	70	78	87.2	100	98	100	100	95	98.6
Dec	100	88	89	98	94	93.8	86	96	100	58	56	79.2	100	98	100	99	96	98.6
Average %	99.5	82	93.6	98.3	93.3	93.34	95.3	98.4	99.1	87.8	91	94.32	99.8	99.4	99.7	99.9	98.3	99.42
Lot Avg %			**93.3**						**94.3**						**99.4**			

Figure B2 - Additional Solar Radiation Exposure Percentages for Top 3 Parking Areas

Appendix C: Solar Radiation Data

Solar radiation, measured in kWh / m^2 / year, varies significantly based on geographic location. Figure C1 compares solar radiation across the United States, and also includes Spain and Germany for further reference (WABE, 2013). Massachusetts gets approximately 1,600 kWh / m^2 / year of solar radiation, comparable to Spain.

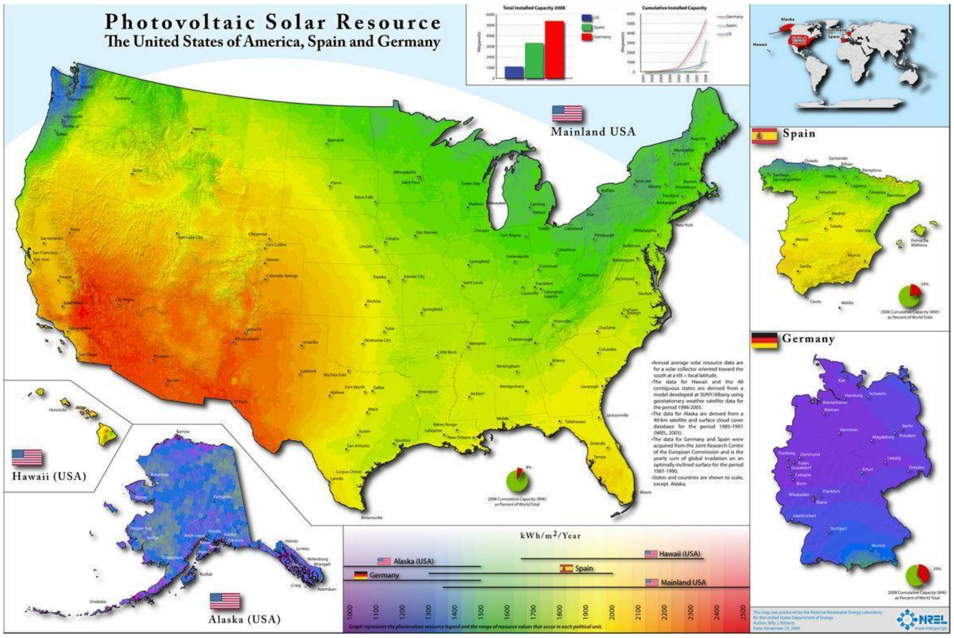


Figure C1 - Solar Radiation in the US, Spain, and Germany (WABE, 2013)

More local data on solar radiation can be found using NREL's calculator for solar systems. Figure C2 depicts typical variance in annual solar radiation on any given year - for example, the system has a 90% chance of generating at least 96% of the typical annual output, and a 10% chance of generating more than 104% of the average (National Renewable Energy Laboratory, 2019). Figure C3 shows average solar radiation by day for the given month, as opposed to the yearly estimate given previously (National Renewable Energy Laboratory, 2019).

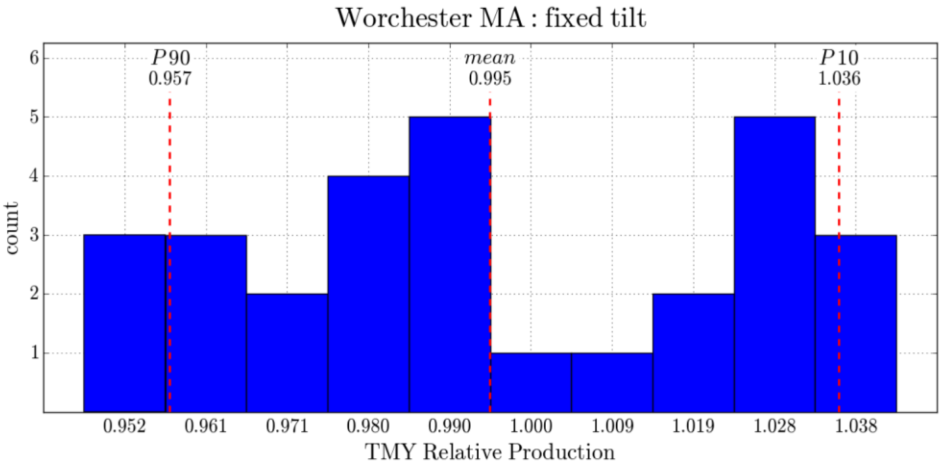


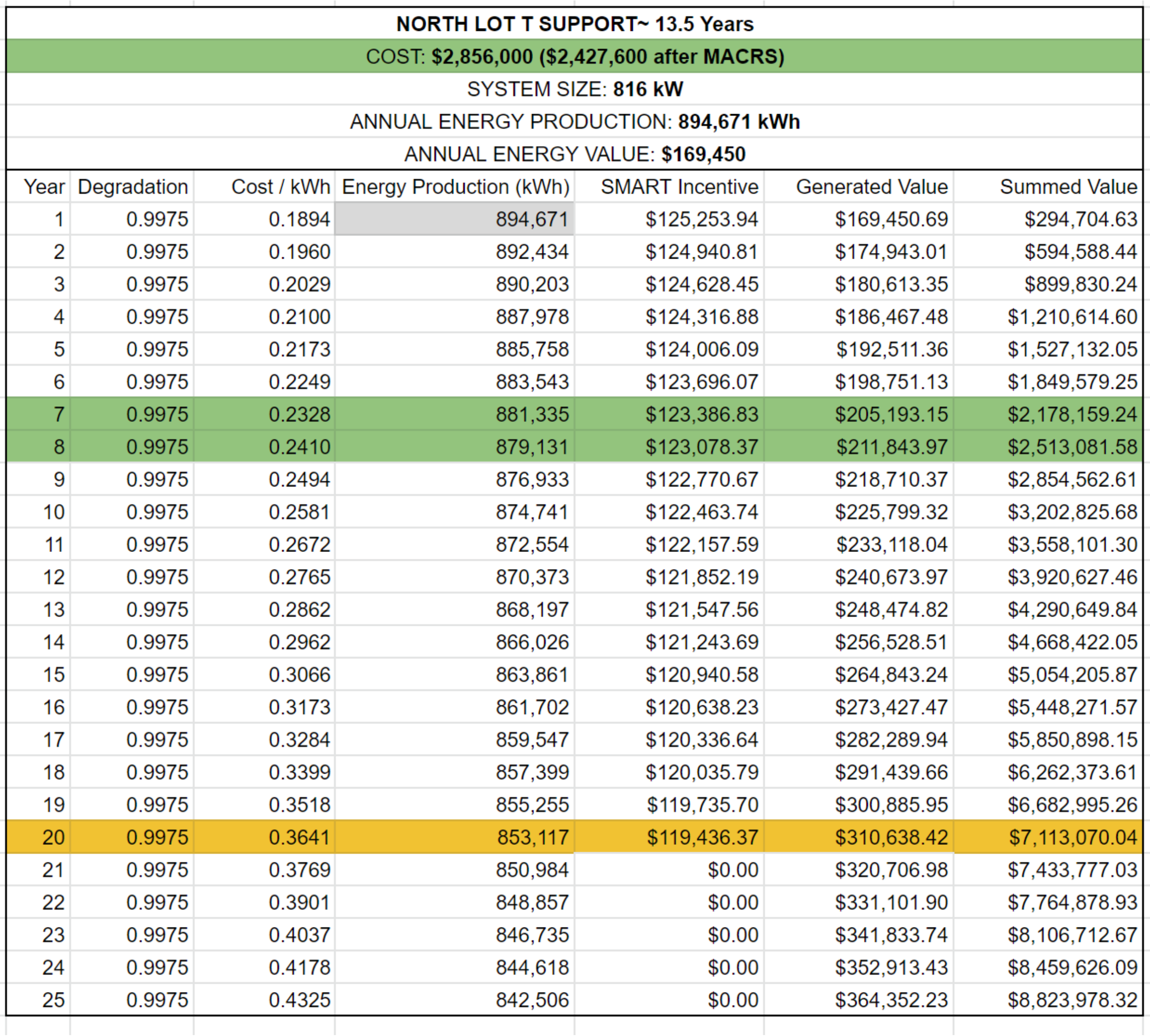
Figure C2 - Solar Radiation Variance in Worcester, MA (National Renewable Energy Laboratory, 2019)

Month	Solar Radiation (kWh / m^2 / day)
January	3.02
February	3.97
March	4.79
April	5.63
May	5.80
June	6.05
July	6.47
August	5.90
September	5.11
October	3.81
November	3.16
December	2.57
Annual	4.69

Figure C3 - Average Daily Solar Radiation by Month in Worcester, MA (National Renewable Energy Laboratory, 2019)

Appendix D: Payback Analysis

Conducting our payback analysis through a number of excel sheets and formulas was a critical part of our cost benefit analysis. These formulas are discussed in section 3.6. Organized below are a full list of our tables and calculations. We did in-depth analyses for our top three location options, with three canopy support options examined for each area for a total of 9 figures.



NORTH LOT T SUPPORT~ 13.5 Years

COST: **$2,856,000 ($2,427,600 after MACRS)**

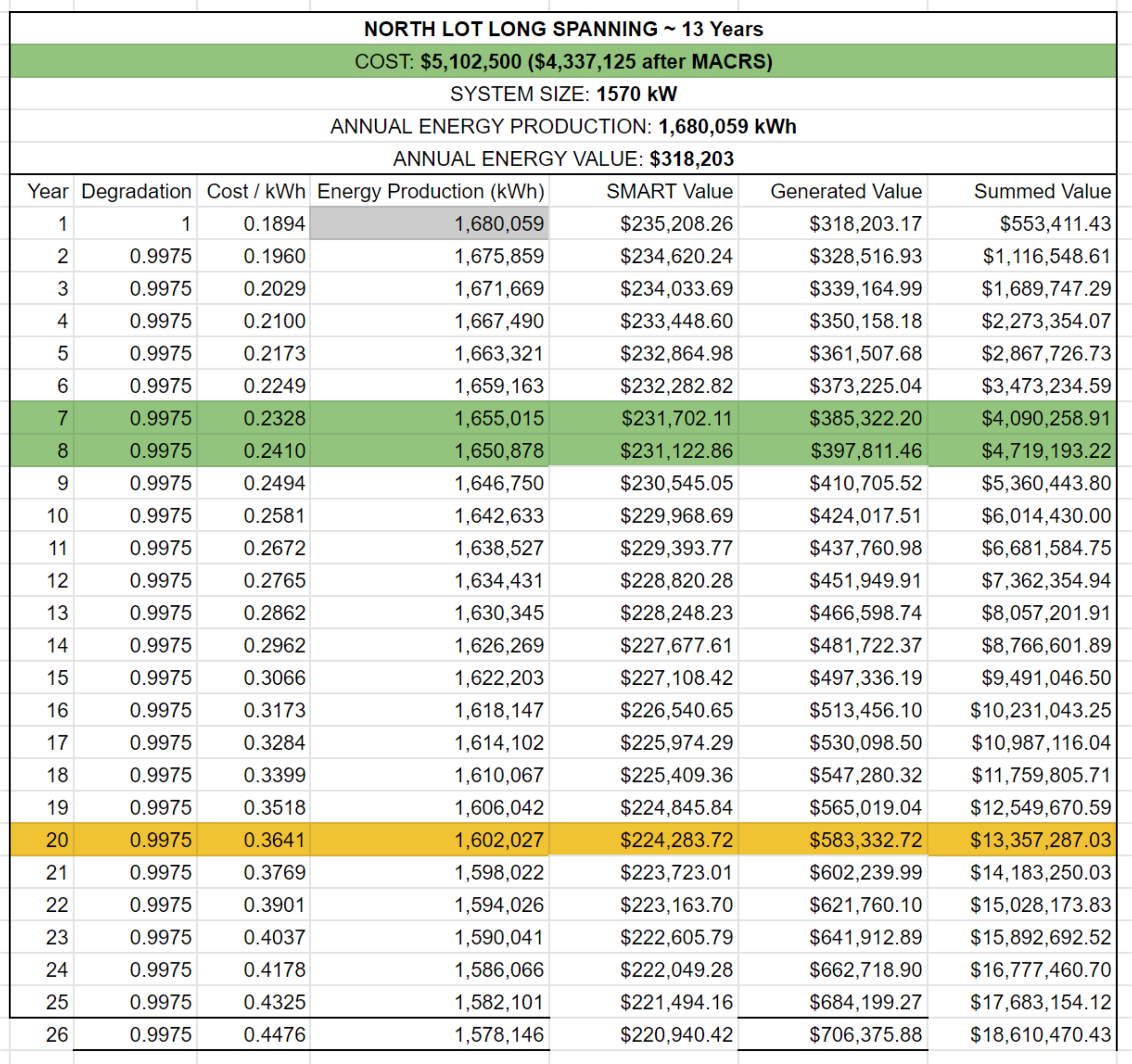
SYSTEM SIZE: **816 kW**

ANNUAL ENERGY PRODUCTION: **894,671 kWh**

ANNUAL ENERGY VALUE: **$169,450**

Year	Degradation	Cost / kWh	Energy Production (kWh)	SMART Incentive	Generated Value	Summed Value
1	0.9975	0.1894	894,671	$125,253.94	$169,450.69	$294,704.63
2	0.9975	0.1960	892,434	$124,940.81	$174,943.01	$594,588.44
3	0.9975	0.2029	890,203	$124,628.45	$180,613.35	$899,830.24
4	0.9975	0.2100	887,978	$124,316.88	$186,467.48	$1,210,614.60
5	0.9975	0.2173	885,758	$124,006.09	$192,511.36	$1,527,132.05
6	0.9975	0.2249	883,543	$123,696.07	$198,751.13	$1,849,579.25
7	0.9975	0.2328	881,335	$123,386.83	$205,193.15	$2,178,159.24
8	0.9975	0.2410	879,131	$123,078.37	$211,843.97	$2,513,081.58
9	0.9975	0.2494	876,933	$122,770.67	$218,710.37	$2,854,562.61
10	0.9975	0.2581	874,741	$122,463.74	$225,799.32	$3,202,825.68
11	0.9975	0.2672	872,554	$122,157.59	$233,118.04	$3,558,101.30
12	0.9975	0.2765	870,373	$121,852.19	$240,673.97	$3,920,627.46
13	0.9975	0.2862	868,197	$121,547.56	$248,474.82	$4,290,649.84
14	0.9975	0.2962	866,026	$121,243.69	$256,528.51	$4,668,422.05
15	0.9975	0.3066	863,861	$120,940.58	$264,843.24	$5,054,205.87
16	0.9975	0.3173	861,702	$120,638.23	$273,427.47	$5,448,271.57
17	0.9975	0.3284	859,547	$120,336.64	$282,289.94	$5,850,898.15
18	0.9975	0.3399	857,399	$120,035.79	$291,439.66	$6,262,373.61
19	0.9975	0.3518	855,255	$119,735.70	$300,885.95	$6,682,995.26
20	0.9975	0.3641	853,117	$119,436.37	$310,638.42	$7,113,070.04
21	0.9975	0.3769	850,984	$0.00	$320,706.98	$7,433,777.03
22	0.9975	0.3901	848,857	$0.00	$331,101.90	$7,764,878.93
23	0.9975	0.4037	846,735	$0.00	$341,833.74	$8,106,712.67
24	0.9975	0.4178	844,618	$0.00	$352,913.43	$8,459,626.09
25	0.9975	0.4325	842,506	$0.00	$364,352.23	$8,823,978.32

Figure D1 - North Lot T Support Canopy Payback Analysis



NORTH LOT LONG SPANNING ~ 13 Years

COST: **$5,102,500 ($4,337,125 after MACRS)**

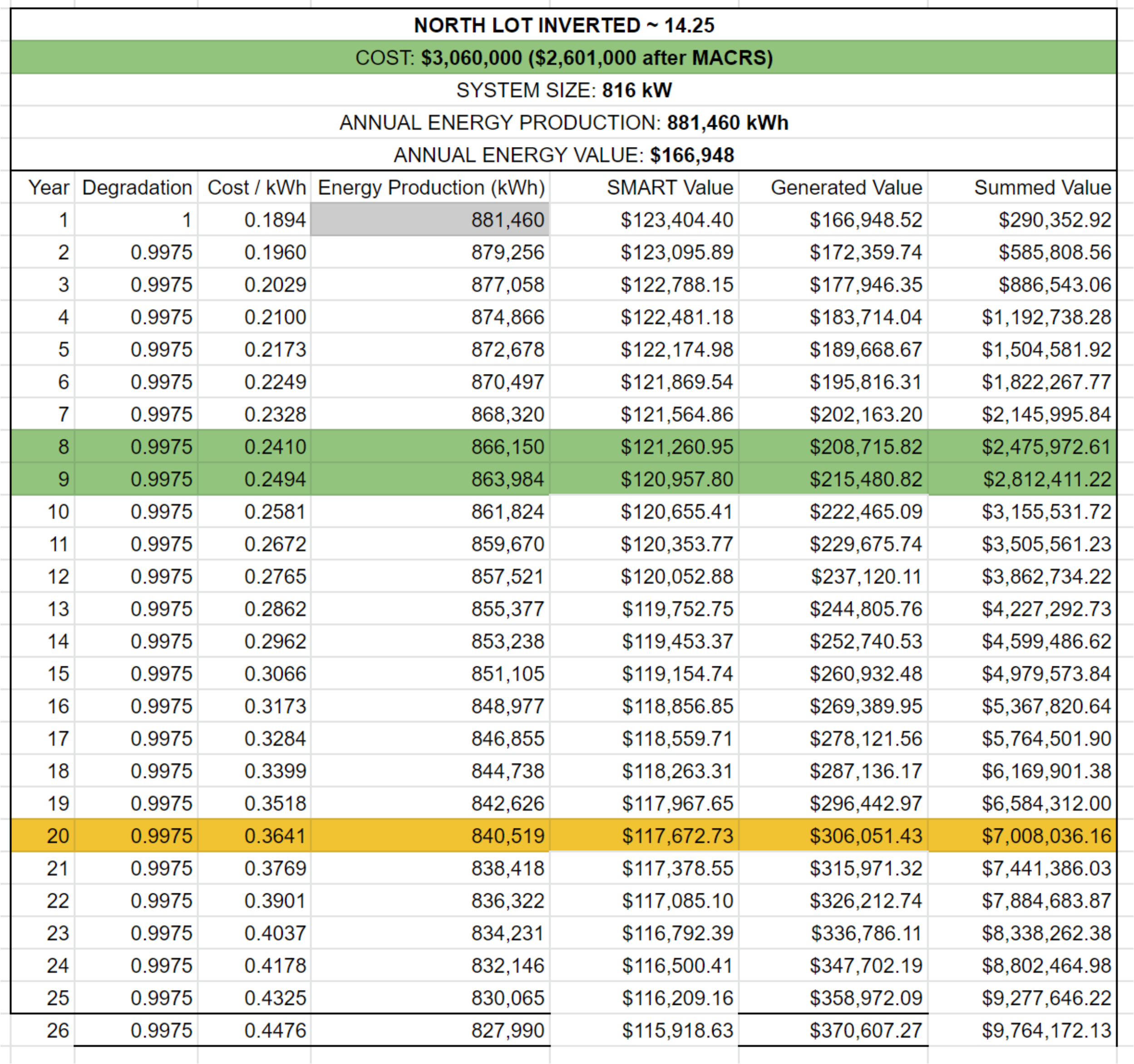
SYSTEM SIZE: **1570 kW**

ANNUAL ENERGY PRODUCTION: **1,680,059 kWh**

ANNUAL ENERGY VALUE: **$318,203**

Year	Degradation	Cost / kWh	Energy Production (kWh)	SMART Value	Generated Value	Summed Value
1	1	0.1894	1,680,059	$235,208.26	$318,203.17	$553,411.43
2	0.9975	0.1960	1,675,859	$234,620.24	$328,516.93	$1,116,548.61
3	0.9975	0.2029	1,671,669	$234,033.69	$339,164.99	$1,689,747.29
4	0.9975	0.2100	1,667,490	$233,448.60	$350,158.18	$2,273,354.07
5	0.9975	0.2173	1,663,321	$232,864.98	$361,507.68	$2,867,726.73
6	0.9975	0.2249	1,659,163	$232,282.82	$373,225.04	$3,473,234.59
7	0.9975	0.2328	1,655,015	$231,702.11	$385,322.20	$4,090,258.91
8	0.9975	0.2410	1,650,878	$231,122.86	$397,811.46	$4,719,193.22
9	0.9975	0.2494	1,646,750	$230,545.05	$410,705.52	$5,360,443.80
10	0.9975	0.2581	1,642,633	$229,968.69	$424,017.51	$6,014,430.00
11	0.9975	0.2672	1,638,527	$229,393.77	$437,760.98	$6,681,584.75
12	0.9975	0.2765	1,634,431	$228,820.28	$451,949.91	$7,362,354.94
13	0.9975	0.2862	1,630,345	$228,248.23	$466,598.74	$8,057,201.91
14	0.9975	0.2962	1,626,269	$227,677.61	$481,722.37	$8,766,601.89
15	0.9975	0.3066	1,622,203	$227,108.42	$497,336.19	$9,491,046.50
16	0.9975	0.3173	1,618,147	$226,540.65	$513,456.10	$10,231,043.25
17	0.9975	0.3284	1,614,102	$225,974.29	$530,098.50	$10,987,116.04
18	0.9975	0.3399	1,610,067	$225,409.36	$547,280.32	$11,759,805.71
19	0.9975	0.3518	1,606,042	$224,845.84	$565,019.04	$12,549,670.59
20	0.9975	0.3641	1,602,027	$224,283.72	$583,332.72	$13,357,287.03
21	0.9975	0.3769	1,598,022	$223,723.01	$602,239.99	$14,183,250.03
22	0.9975	0.3901	1,594,026	$223,163.70	$621,760.10	$15,028,173.83
23	0.9975	0.4037	1,590,041	$222,605.79	$641,912.89	$15,892,692.52
24	0.9975	0.4178	1,586,066	$222,049.28	$662,718.90	$16,777,460.70
25	0.9975	0.4325	1,582,101	$221,494.16	$684,199.27	$17,683,154.12
26	0.9975	0.4476	1,578,146	$220,940.42	$706,375.88	$18,610,470.43

Figure D2 - North Lot Long Spanning Canopy Payback Analysis



NORTH LOT INVERTED ~ 14.25

COST: **$3,060,000 ($2,601,000 after MACRS)**

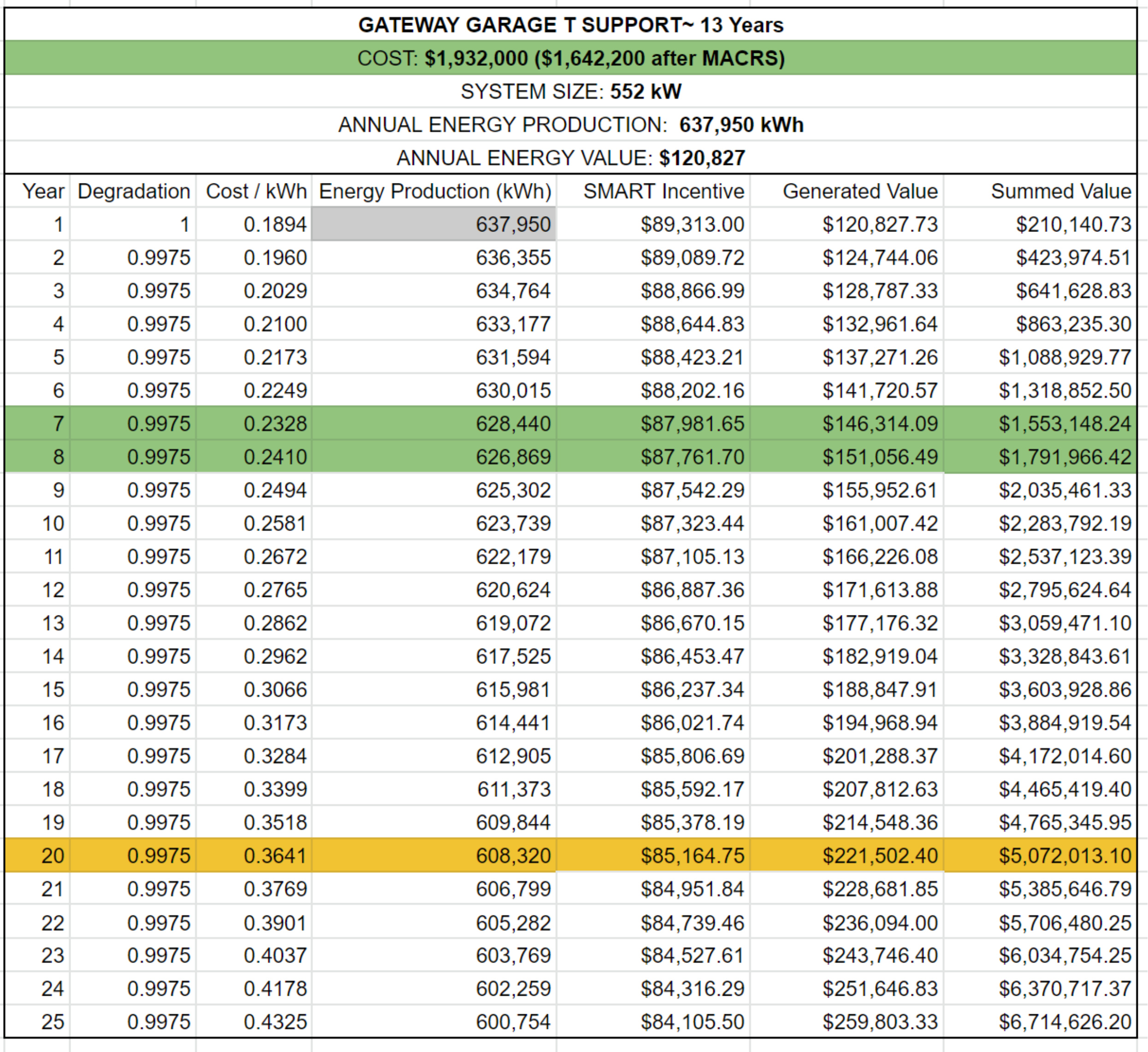
SYSTEM SIZE: **816 kW**

ANNUAL ENERGY PRODUCTION: **881,460 kWh**

ANNUAL ENERGY VALUE: **$166,948**

Year	Degradation	Cost / kWh	Energy Production (kWh)	SMART Value	Generated Value	Summed Value
1	1	0.1894	881,460	$123,404.40	$166,948.52	$290,352.92
2	0.9975	0.1960	879,256	$123,095.89	$172,359.74	$585,808.56
3	0.9975	0.2029	877,058	$122,788.15	$177,946.35	$886,543.06
4	0.9975	0.2100	874,866	$122,481.18	$183,714.04	$1,192,738.28
5	0.9975	0.2173	872,678	$122,174.98	$189,668.67	$1,504,581.92
6	0.9975	0.2249	870,497	$121,869.54	$195,816.31	$1,822,267.77
7	0.9975	0.2328	868,320	$121,564.86	$202,163.20	$2,145,995.84
8	0.9975	0.2410	866,150	$121,260.95	$208,715.82	$2,475,972.61
9	0.9975	0.2494	863,984	$120,957.80	$215,480.82	$2,812,411.22
10	0.9975	0.2581	861,824	$120,655.41	$222,465.09	$3,155,531.72
11	0.9975	0.2672	859,670	$120,353.77	$229,675.74	$3,505,561.23
12	0.9975	0.2765	857,521	$120,052.88	$237,120.11	$3,862,734.22
13	0.9975	0.2862	855,377	$119,752.75	$244,805.76	$4,227,292.73
14	0.9975	0.2962	853,238	$119,453.37	$252,740.53	$4,599,486.62
15	0.9975	0.3066	851,105	$119,154.74	$260,932.48	$4,979,573.84
16	0.9975	0.3173	848,977	$118,856.85	$269,389.95	$5,367,820.64
17	0.9975	0.3284	846,855	$118,559.71	$278,121.56	$5,764,501.90
18	0.9975	0.3399	844,738	$118,263.31	$287,136.17	$6,169,901.38
19	0.9975	0.3518	842,626	$117,967.65	$296,442.97	$6,584,312.00
20	0.9975	0.3641	840,519	$117,672.73	$306,051.43	$7,008,036.16
21	0.9975	0.3769	838,418	$117,378.55	$315,971.32	$7,441,386.03
22	0.9975	0.3901	836,322	$117,085.10	$326,212.74	$7,884,683.87
23	0.9975	0.4037	834,231	$116,792.39	$336,786.11	$8,338,262.38
24	0.9975	0.4178	832,146	$116,500.41	$347,702.19	$8,802,464.98
25	0.9975	0.4325	830,065	$116,209.16	$358,972.09	$9,277,646.22
26	0.9975	0.4476	827,990	$115,918.63	$370,607.27	$9,764,172.13

Figure D3 - North Lot Inverted Canopy Payback Analysis



GATEWAY GARAGE T SUPPORT~ 13 Years

COST: **$1,932,000 ($1,642,200 after MACRS)**

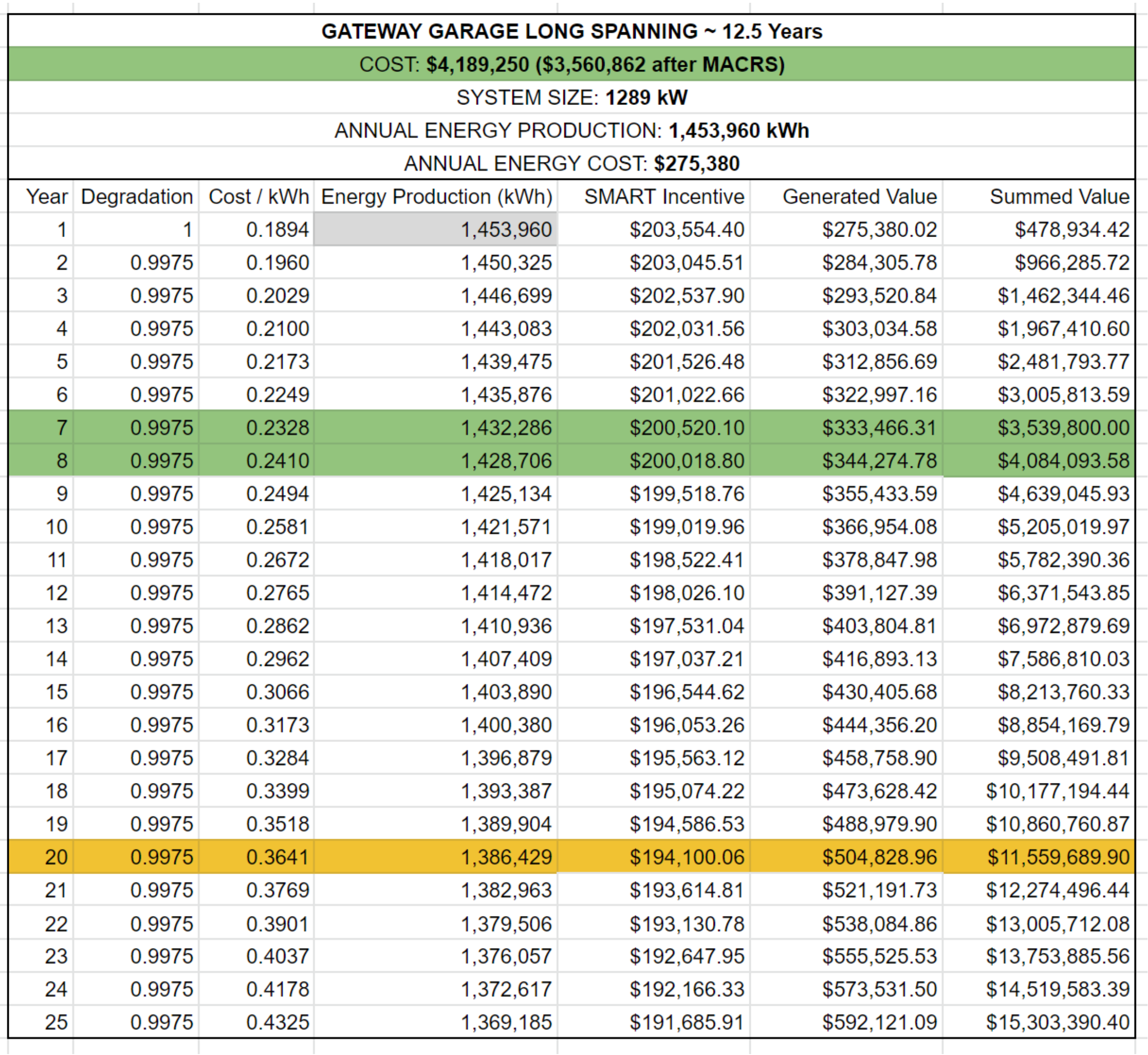
SYSTEM SIZE: **552 kW**

ANNUAL ENERGY PRODUCTION: **637,950 kWh**

ANNUAL ENERGY VALUE: **$120,827**

Year	Degradation	Cost / kWh	Energy Production (kWh)	SMART Incentive	Generated Value	Summed Value
1	1	0.1894	637,950	$89,313.00	$120,827.73	$210,140.73
2	0.9975	0.1960	636,355	$89,089.72	$124,744.06	$423,974.51
3	0.9975	0.2029	634,764	$88,866.99	$128,787.33	$641,628.83
4	0.9975	0.2100	633,177	$88,644.83	$132,961.64	$863,235.30
5	0.9975	0.2173	631,594	$88,423.21	$137,271.26	$1,088,929.77
6	0.9975	0.2249	630,015	$88,202.16	$141,720.57	$1,318,852.50
7	0.9975	0.2328	628,440	$87,981.65	$146,314.09	$1,553,148.24
8	0.9975	0.2410	626,869	$87,761.70	$151,056.49	$1,791,966.42
9	0.9975	0.2494	625,302	$87,542.29	$155,952.61	$2,035,461.33
10	0.9975	0.2581	623,739	$87,323.44	$161,007.42	$2,283,792.19
11	0.9975	0.2672	622,179	$87,105.13	$166,226.08	$2,537,123.39
12	0.9975	0.2765	620,624	$86,887.36	$171,613.88	$2,795,624.64
13	0.9975	0.2862	619,072	$86,670.15	$177,176.32	$3,059,471.10
14	0.9975	0.2962	617,525	$86,453.47	$182,919.04	$3,328,843.61
15	0.9975	0.3066	615,981	$86,237.34	$188,847.91	$3,603,928.86
16	0.9975	0.3173	614,441	$86,021.74	$194,968.94	$3,884,919.54
17	0.9975	0.3284	612,905	$85,806.69	$201,288.37	$4,172,014.60
18	0.9975	0.3399	611,373	$85,592.17	$207,812.63	$4,465,419.40
19	0.9975	0.3518	609,844	$85,378.19	$214,548.36	$4,765,345.95
20	0.9975	0.3641	608,320	$85,164.75	$221,502.40	$5,072,013.10
21	0.9975	0.3769	606,799	$84,951.84	$228,681.85	$5,385,646.79
22	0.9975	0.3901	605,282	$84,739.46	$236,094.00	$5,706,480.25
23	0.9975	0.4037	603,769	$84,527.61	$243,746.40	$6,034,754.25
24	0.9975	0.4178	602,259	$84,316.29	$251,646.83	$6,370,717.37
25	0.9975	0.4325	600,754	$84,105.50	$259,803.33	$6,714,626.20

Figure D4 - Gateway Garage T Support Canopy Payback Analysis



GATEWAY GARAGE LONG SPANNING ~ 12.5 Years

COST: **$4,189,250 ($3,560,862 after MACRS)**

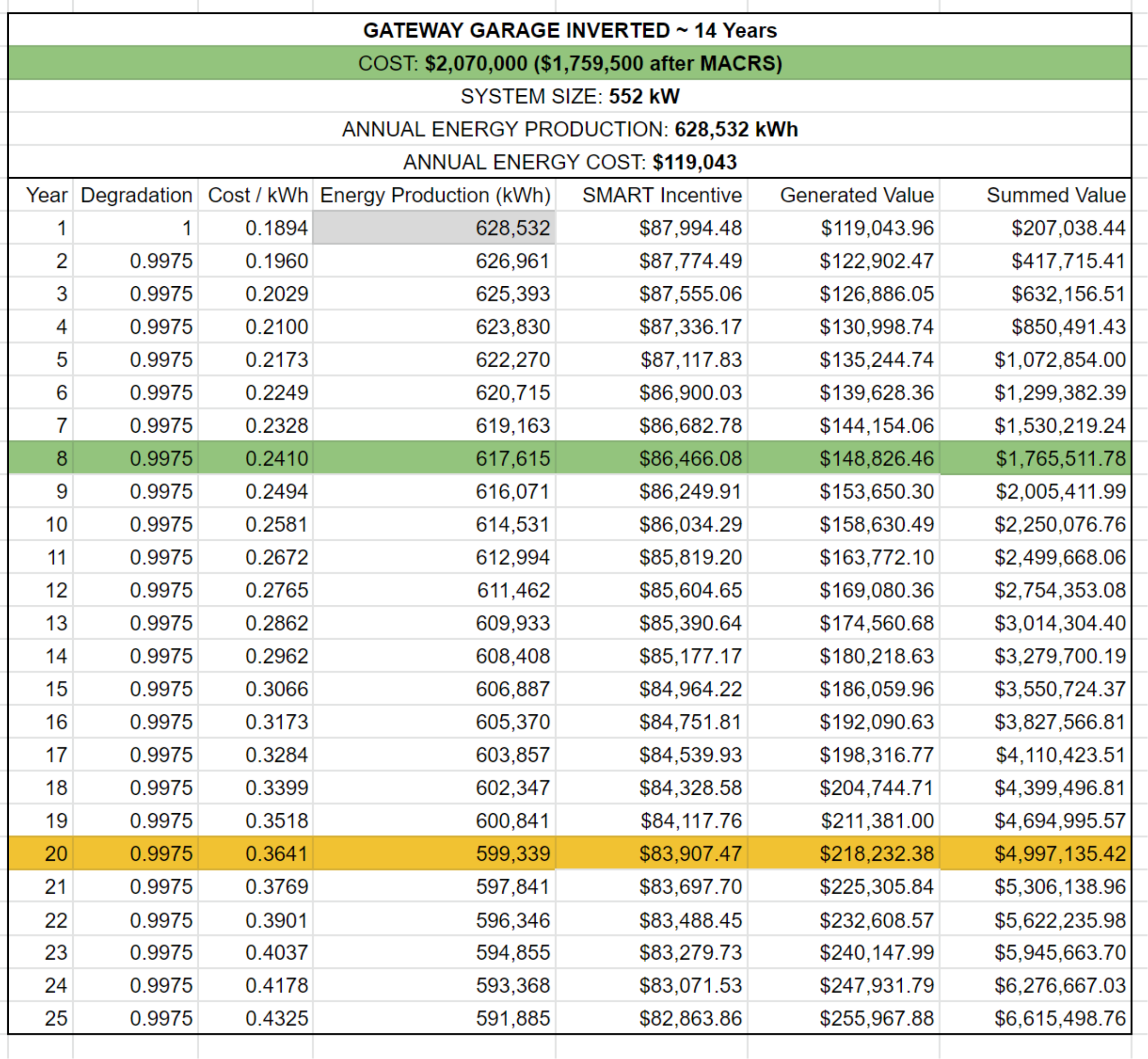
SYSTEM SIZE: **1289 kW**

ANNUAL ENERGY PRODUCTION: **1,453,960 kWh**

ANNUAL ENERGY COST: **$275,380**

Year	Degradation	Cost / kWh	Energy Production (kWh)	SMART Incentive	Generated Value	Summed Value
1	1	0.1894	1,453,960	$203,554.40	$275,380.02	$478,934.42
2	0.9975	0.1960	1,450,325	$203,045.51	$284,305.78	$966,285.72
3	0.9975	0.2029	1,446,699	$202,537.90	$293,520.84	$1,462,344.46
4	0.9975	0.2100	1,443,083	$202,031.56	$303,034.58	$1,967,410.60
5	0.9975	0.2173	1,439,475	$201,526.48	$312,856.69	$2,481,793.77
6	0.9975	0.2249	1,435,876	$201,022.66	$322,997.16	$3,005,813.59
7	0.9975	0.2328	1,432,286	$200,520.10	$333,466.31	$3,539,800.00
8	0.9975	0.2410	1,428,706	$200,018.80	$344,274.78	$4,084,093.58
9	0.9975	0.2494	1,425,134	$199,518.76	$355,433.59	$4,639,045.93
10	0.9975	0.2581	1,421,571	$199,019.96	$366,954.08	$5,205,019.97
11	0.9975	0.2672	1,418,017	$198,522.41	$378,847.98	$5,782,390.36
12	0.9975	0.2765	1,414,472	$198,026.10	$391,127.39	$6,371,543.85
13	0.9975	0.2862	1,410,936	$197,531.04	$403,804.81	$6,972,879.69
14	0.9975	0.2962	1,407,409	$197,037.21	$416,893.13	$7,586,810.03
15	0.9975	0.3066	1,403,890	$196,544.62	$430,405.68	$8,213,760.33
16	0.9975	0.3173	1,400,380	$196,053.26	$444,356.20	$8,854,169.79
17	0.9975	0.3284	1,396,879	$195,563.12	$458,758.90	$9,508,491.81
18	0.9975	0.3399	1,393,387	$195,074.22	$473,628.42	$10,177,194.44
19	0.9975	0.3518	1,389,904	$194,586.53	$488,979.90	$10,860,760.87
20	0.9975	0.3641	1,386,429	$194,100.06	$504,828.96	$11,559,689.90
21	0.9975	0.3769	1,382,963	$193,614.81	$521,191.73	$12,274,496.44
22	0.9975	0.3901	1,379,506	$193,130.78	$538,084.86	$13,005,712.08
23	0.9975	0.4037	1,376,057	$192,647.95	$555,525.53	$13,753,885.56
24	0.9975	0.4178	1,372,617	$192,166.33	$573,531.50	$14,519,583.39
25	0.9975	0.4325	1,369,185	$191,685.91	$592,121.09	$15,303,390.40

Figure D5 - Gateway Garage Long Spanning Canopy Payback Analysis



GATEWAY GARAGE INVERTED ~ 14 Years

COST: **$2,070,000 ($1,759,500 after MACRS)**

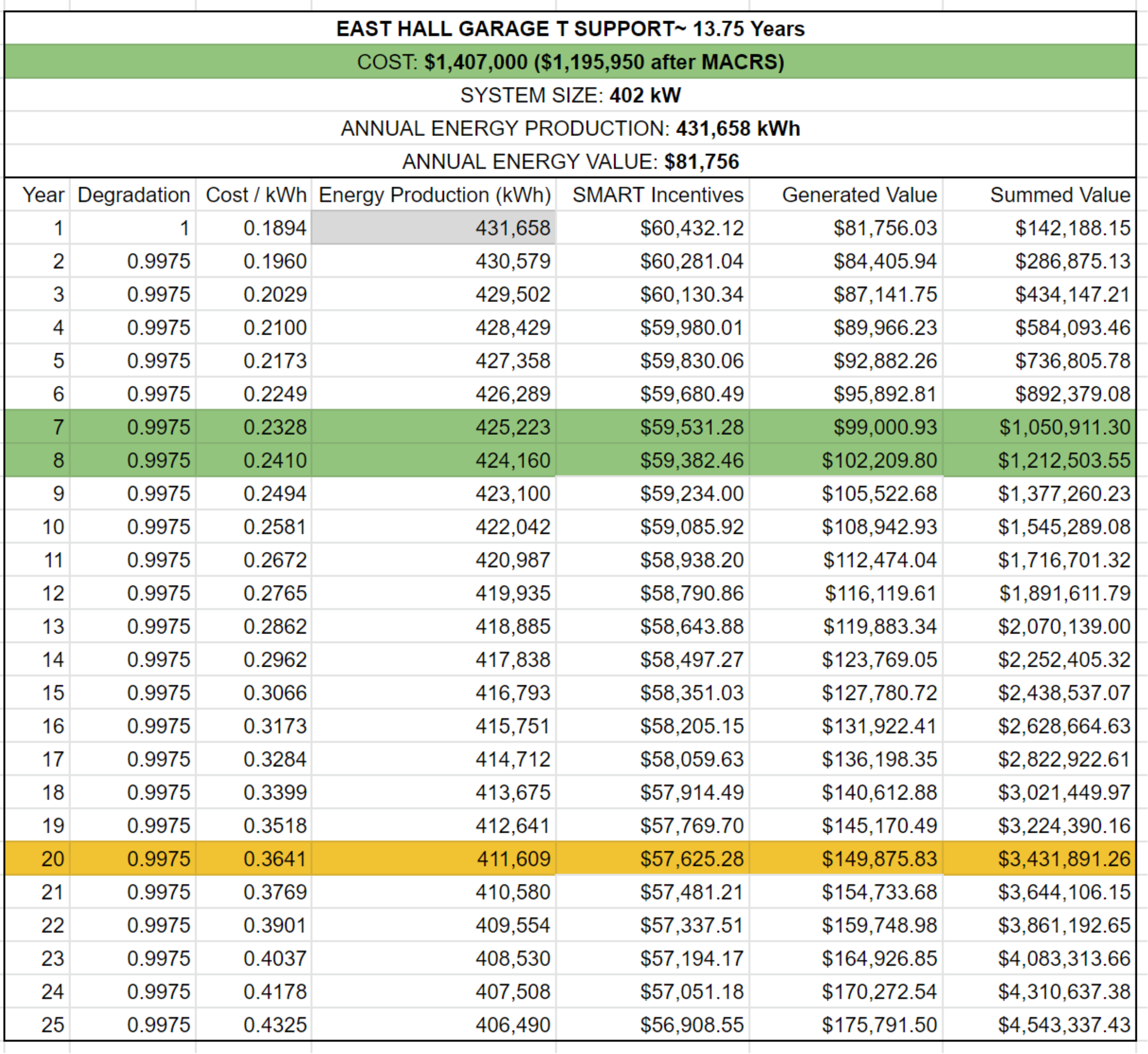
SYSTEM SIZE: **552 kW**

ANNUAL ENERGY PRODUCTION: **628,532 kWh**

ANNUAL ENERGY COST: **$119,043**

Year	Degradation	Cost / kWh	Energy Production (kWh)	SMART Incentive	Generated Value	Summed Value
1	1	0.1894	628,532	$87,994.48	$119,043.96	$207,038.44
2	0.9975	0.1960	626,961	$87,774.49	$122,902.47	$417,715.41
3	0.9975	0.2029	625,393	$87,555.06	$126,886.05	$632,156.51
4	0.9975	0.2100	623,830	$87,336.17	$130,998.74	$850,491.43
5	0.9975	0.2173	622,270	$87,117.83	$135,244.74	$1,072,854.00
6	0.9975	0.2249	620,715	$86,900.03	$139,628.36	$1,299,382.39
7	0.9975	0.2328	619,163	$86,682.78	$144,154.06	$1,530,219.24
8	0.9975	0.2410	617,615	$86,466.08	$148,826.46	$1,765,511.78
9	0.9975	0.2494	616,071	$86,249.91	$153,650.30	$2,005,411.99
10	0.9975	0.2581	614,531	$86,034.29	$158,630.49	$2,250,076.76
11	0.9975	0.2672	612,994	$85,819.20	$163,772.10	$2,499,668.06
12	0.9975	0.2765	611,462	$85,604.65	$169,080.36	$2,754,353.08
13	0.9975	0.2862	609,933	$85,390.64	$174,560.68	$3,014,304.40
14	0.9975	0.2962	608,408	$85,177.17	$180,218.63	$3,279,700.19
15	0.9975	0.3066	606,887	$84,964.22	$186,059.96	$3,550,724.37
16	0.9975	0.3173	605,370	$84,751.81	$192,090.63	$3,827,566.81
17	0.9975	0.3284	603,857	$84,539.93	$198,316.77	$4,110,423.51
18	0.9975	0.3399	602,347	$84,328.58	$204,744.71	$4,399,496.81
19	0.9975	0.3518	600,841	$84,117.76	$211,381.00	$4,694,995.57
20	0.9975	0.3641	599,339	$83,907.47	$218,232.38	$4,997,135.42
21	0.9975	0.3769	597,841	$83,697.70	$225,305.84	$5,306,138.96
22	0.9975	0.3901	596,346	$83,488.45	$232,608.57	$5,622,235.98
23	0.9975	0.4037	594,855	$83,279.73	$240,147.99	$5,945,663.70
24	0.9975	0.4178	593,368	$83,071.53	$247,931.79	$6,276,667.03
25	0.9975	0.4325	591,885	$82,863.86	$255,967.88	$6,615,498.76

Figure D6 - Gateway Garage Inverted Canopy Payback Analysis



EAST HALL GARAGE T SUPPORT~ 13.75 Years

COST: **$1,407,000 ($1,195,950 after MACRS)**

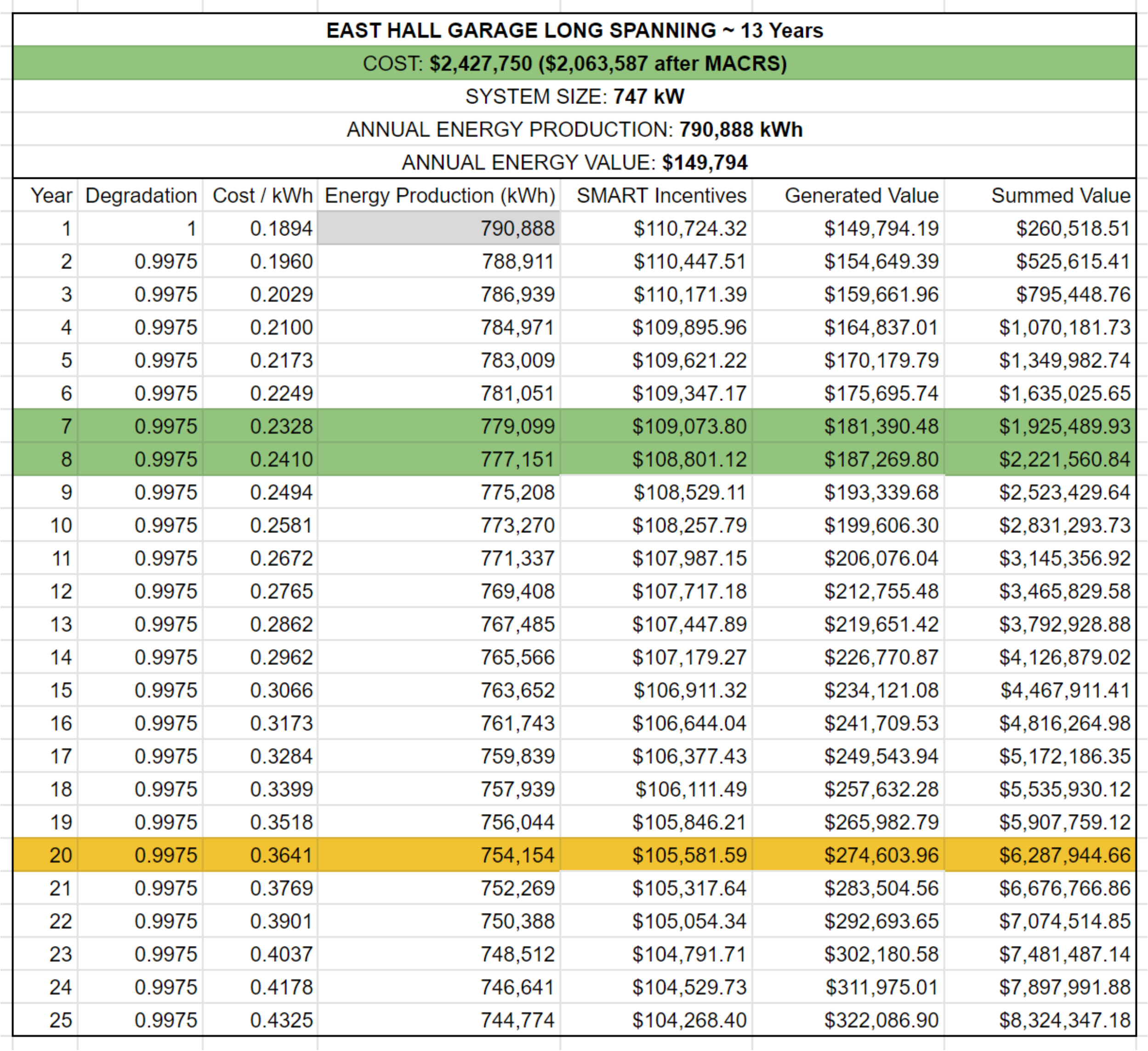
SYSTEM SIZE: **402 kW**

ANNUAL ENERGY PRODUCTION: **431,658 kWh**

ANNUAL ENERGY VALUE: **$81,756**

Year	Degradation	Cost / kWh	Energy Production (kWh)	SMART Incentives	Generated Value	Summed Value
1	1	0.1894	431,658	$60,432.12	$81,756.03	$142,188.15
2	0.9975	0.1960	430,579	$60,281.04	$84,405.94	$286,875.13
3	0.9975	0.2029	429,502	$60,130.34	$87,141.75	$434,147.21
4	0.9975	0.2100	428,429	$59,980.01	$89,966.23	$584,093.46
5	0.9975	0.2173	427,358	$59,830.06	$92,882.26	$736,805.78
6	0.9975	0.2249	426,289	$59,680.49	$95,892.81	$892,379.08
7	0.9975	0.2328	425,223	$59,531.28	$99,000.93	$1,050,911.30
8	0.9975	0.2410	424,160	$59,382.46	$102,209.80	$1,212,503.55
9	0.9975	0.2494	423,100	$59,234.00	$105,522.68	$1,377,260.23
10	0.9975	0.2581	422,042	$59,085.92	$108,942.93	$1,545,289.08
11	0.9975	0.2672	420,987	$58,938.20	$112,474.04	$1,716,701.32
12	0.9975	0.2765	419,935	$58,790.86	$116,119.61	$1,891,611.79
13	0.9975	0.2862	418,885	$58,643.88	$119,883.34	$2,070,139.00
14	0.9975	0.2962	417,838	$58,497.27	$123,769.05	$2,252,405.32
15	0.9975	0.3066	416,793	$58,351.03	$127,780.72	$2,438,537.07
16	0.9975	0.3173	415,751	$58,205.15	$131,922.41	$2,628,664.63
17	0.9975	0.3284	414,712	$58,059.63	$136,198.35	$2,822,922.61
18	0.9975	0.3399	413,675	$57,914.49	$140,612.88	$3,021,449.97
19	0.9975	0.3518	412,641	$57,769.70	$145,170.49	$3,224,390.16
20	0.9975	0.3641	411,609	$57,625.28	$149,875.83	$3,431,891.26
21	0.9975	0.3769	410,580	$57,481.21	$154,733.68	$3,644,106.15
22	0.9975	0.3901	409,554	$57,337.51	$159,748.98	$3,861,192.65
23	0.9975	0.4037	408,530	$57,194.17	$164,926.85	$4,083,313.66
24	0.9975	0.4178	407,508	$57,051.18	$170,272.54	$4,310,637.38
25	0.9975	0.4325	406,490	$56,908.55	$175,791.50	$4,543,337.43

Figure D7 - East Hall Garage T Support Canopy Payback Analysis



EAST HALL GARAGE LONG SPANNING ~ 13 Years

COST: **$2,427,750 ($2,063,587 after MACRS)**

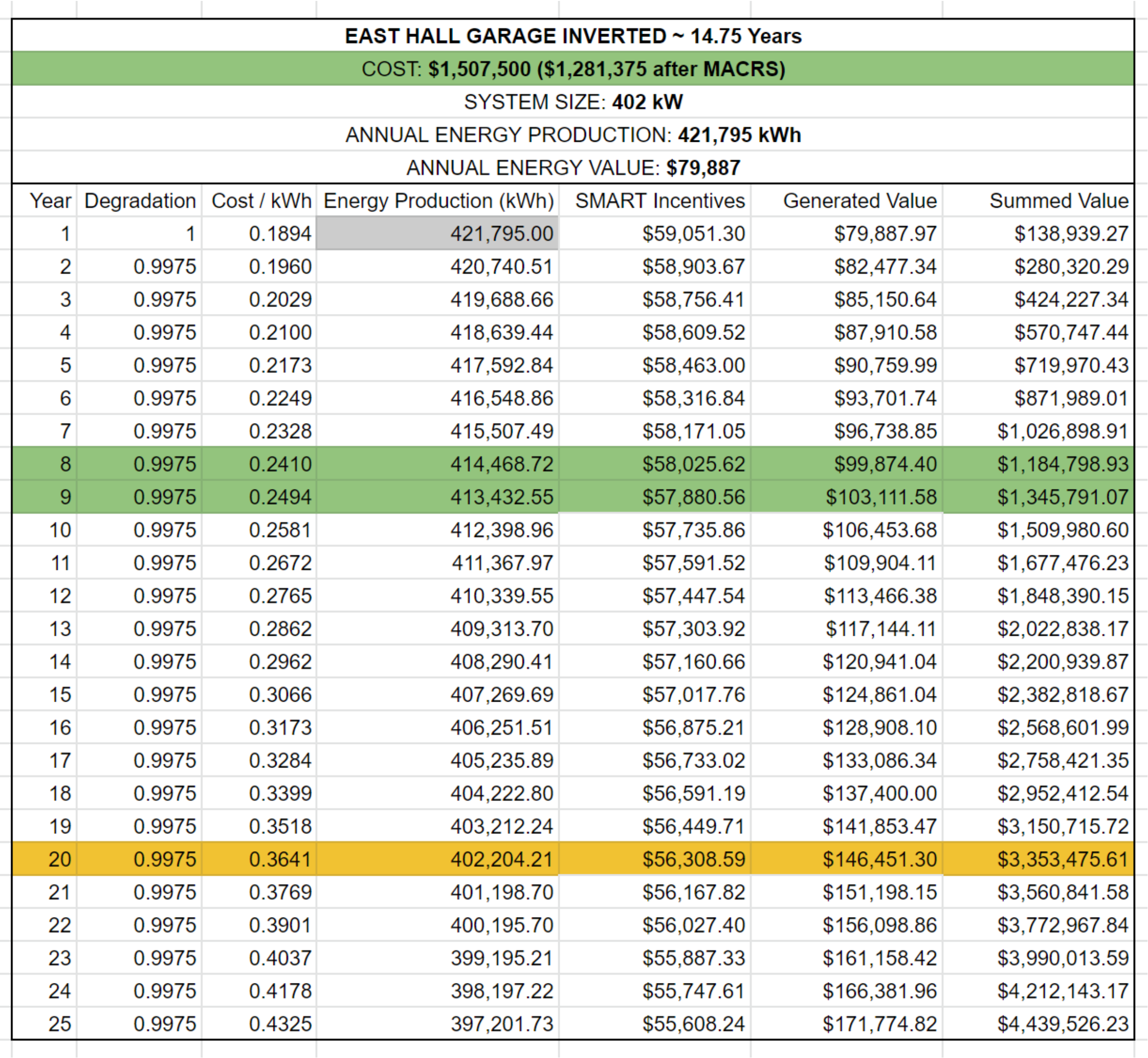
SYSTEM SIZE: **747 kW**

ANNUAL ENERGY PRODUCTION: **790,888 kWh**

ANNUAL ENERGY VALUE: **$149,794**

Year	Degradation	Cost / kWh	Energy Production (kWh)	SMART Incentives	Generated Value	Summed Value
1	1	0.1894	790,888	$110,724.32	$149,794.19	$260,518.51
2	0.9975	0.1960	788,911	$110,447.51	$154,649.39	$525,615.41
3	0.9975	0.2029	786,939	$110,171.39	$159,661.96	$795,448.76
4	0.9975	0.2100	784,971	$109,895.96	$164,837.01	$1,070,181.73
5	0.9975	0.2173	783,009	$109,621.22	$170,179.79	$1,349,982.74
6	0.9975	0.2249	781,051	$109,347.17	$175,695.74	$1,635,025.65
7	0.9975	0.2328	779,099	$109,073.80	$181,390.48	$1,925,489.93
8	0.9975	0.2410	777,151	$108,801.12	$187,269.80	$2,221,560.84
9	0.9975	0.2494	775,208	$108,529.11	$193,339.68	$2,523,429.64
10	0.9975	0.2581	773,270	$108,257.79	$199,606.30	$2,831,293.73
11	0.9975	0.2672	771,337	$107,987.15	$206,076.04	$3,145,356.92
12	0.9975	0.2765	769,408	$107,717.18	$212,755.48	$3,465,829.58
13	0.9975	0.2862	767,485	$107,447.89	$219,651.42	$3,792,928.88
14	0.9975	0.2962	765,566	$107,179.27	$226,770.87	$4,126,879.02
15	0.9975	0.3066	763,652	$106,911.32	$234,121.08	$4,467,911.41
16	0.9975	0.3173	761,743	$106,644.04	$241,709.53	$4,816,264.98
17	0.9975	0.3284	759,839	$106,377.43	$249,543.94	$5,172,186.35
18	0.9975	0.3399	757,939	$106,111.49	$257,632.28	$5,535,930.12
19	0.9975	0.3518	756,044	$105,846.21	$265,982.79	$5,907,759.12
20	0.9975	0.3641	754,154	$105,581.59	$274,603.96	$6,287,944.66
21	0.9975	0.3769	752,269	$105,317.64	$283,504.56	$6,676,766.86
22	0.9975	0.3901	750,388	$105,054.34	$292,693.65	$7,074,514.85
23	0.9975	0.4037	748,512	$104,791.71	$302,180.58	$7,481,487.14
24	0.9975	0.4178	746,641	$104,529.73	$311,975.01	$7,897,991.88
25	0.9975	0.4325	744,774	$104,268.40	$322,086.90	$8,324,347.18

Figure D8 - East Hall Garage Long Spanning Canopy Payback Analysis



EAST HALL GARAGE INVERTED ~ 14.75 Years

COST: **$1,507,500 ($1,281,375 after MACRS)**

SYSTEM SIZE: **402 kW**

ANNUAL ENERGY PRODUCTION: **421,795 kWh**

ANNUAL ENERGY VALUE: **$79,887**

Year	Degradation	Cost / kWh	Energy Production (kWh)	SMART Incentives	Generated Value	Summed Value
1	1	0.1894	421,795.00	$59,051.30	$79,887.97	$138,939.27
2	0.9975	0.1960	420,740.51	$58,903.67	$82,477.34	$280,320.29
3	0.9975	0.2029	419,688.66	$58,756.41	$85,150.64	$424,227.34
4	0.9975	0.2100	418,639.44	$58,609.52	$87,910.58	$570,747.44
5	0.9975	0.2173	417,592.84	$58,463.00	$90,759.99	$719,970.43
6	0.9975	0.2249	416,548.86	$58,316.84	$93,701.74	$871,989.01
7	0.9975	0.2328	415,507.49	$58,171.05	$96,738.85	$1,026,898.91
8	0.9975	0.2410	414,468.72	$58,025.62	$99,874.40	$1,184,798.93
9	0.9975	0.2494	413,432.55	$57,880.56	$103,111.58	$1,345,791.07
10	0.9975	0.2581	412,398.96	$57,735.86	$106,453.68	$1,509,980.60
11	0.9975	0.2672	411,367.97	$57,591.52	$109,904.11	$1,677,476.23
12	0.9975	0.2765	410,339.55	$57,447.54	$113,466.38	$1,848,390.15
13	0.9975	0.2862	409,313.70	$57,303.92	$117,144.11	$2,022,838.17
14	0.9975	0.2962	408,290.41	$57,160.66	$120,941.04	$2,200,939.87
15	0.9975	0.3066	407,269.69	$57,017.76	$124,861.04	$2,382,818.67
16	0.9975	0.3173	406,251.51	$56,875.21	$128,908.10	$2,568,601.99
17	0.9975	0.3284	405,235.89	$56,733.02	$133,086.34	$2,758,421.35
18	0.9975	0.3399	404,222.80	$56,591.19	$137,400.00	$2,952,412.54
19	0.9975	0.3518	403,212.24	$56,449.71	$141,853.47	$3,150,715.72
20	0.9975	0.3641	402,204.21	$56,308.59	$146,451.30	$3,353,475.61
21	0.9975	0.3769	401,198.70	$56,167.82	$151,198.15	$3,560,841.58
22	0.9975	0.3901	400,195.70	$56,027.40	$156,098.86	$3,772,967.84
23	0.9975	0.4037	399,195.21	$55,887.33	$161,158.42	$3,990,013.59
24	0.9975	0.4178	398,197.22	$55,747.61	$166,381.96	$4,212,143.17
25	0.9975	0.4325	397,201.73	$55,608.24	$171,774.82	$4,439,526.23

Figure D9 - East Hall Garage Inverted Canopy Payback Analysis

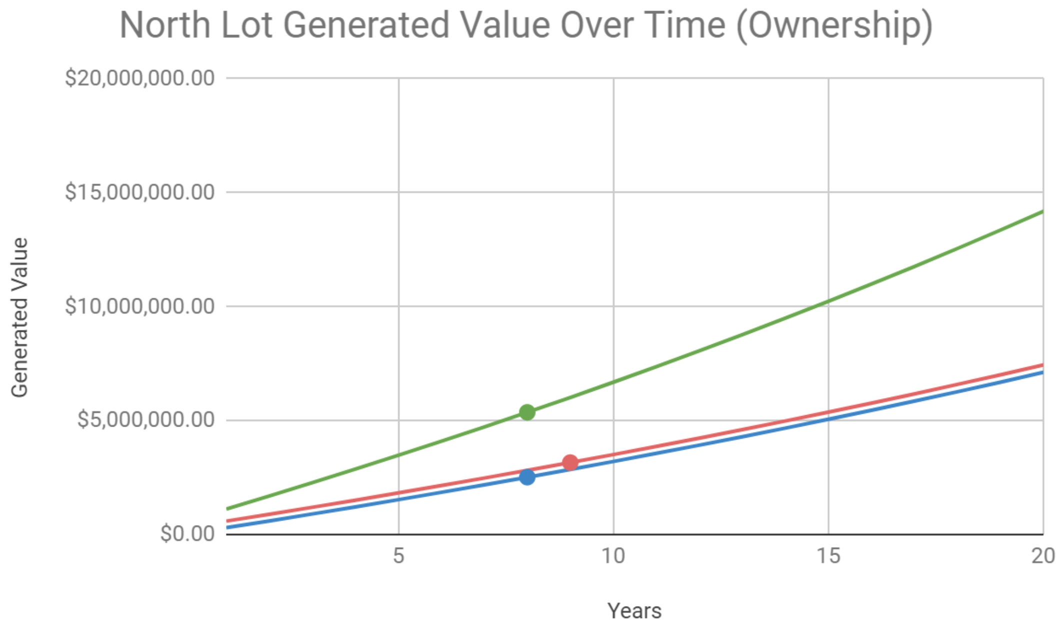


Figure D10 - North Lot Generated Value Over Time for Ownership Graph

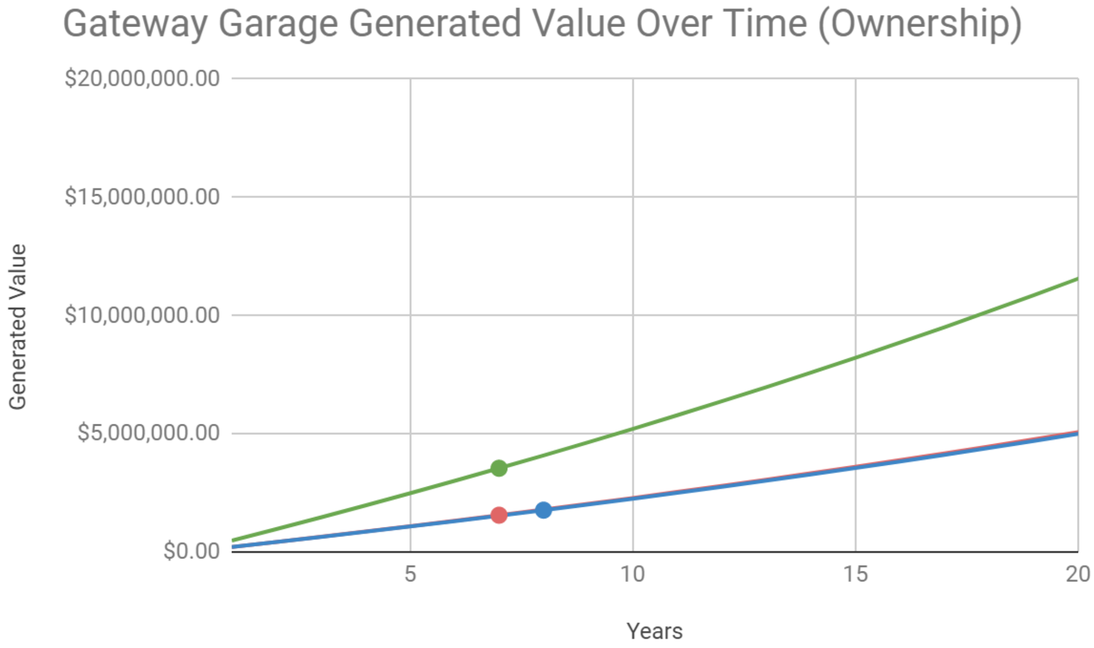


Figure D11 - Gateway Garage Generated Value Over Time for Ownership Graph

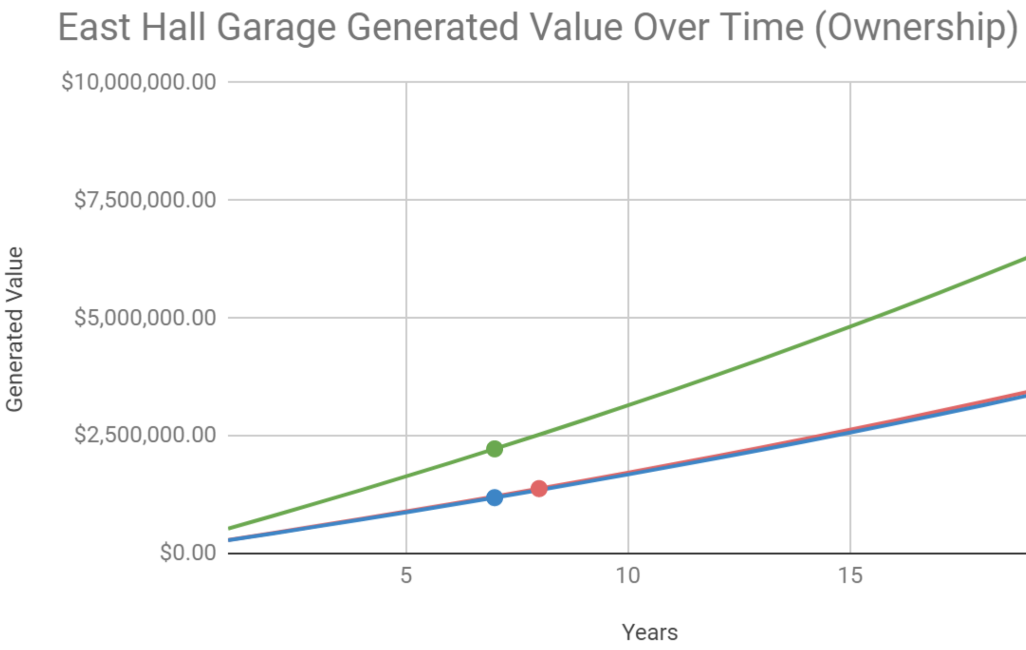


Figure D12 - East Hall Garage Generated Value Over Time for Ownership Graph

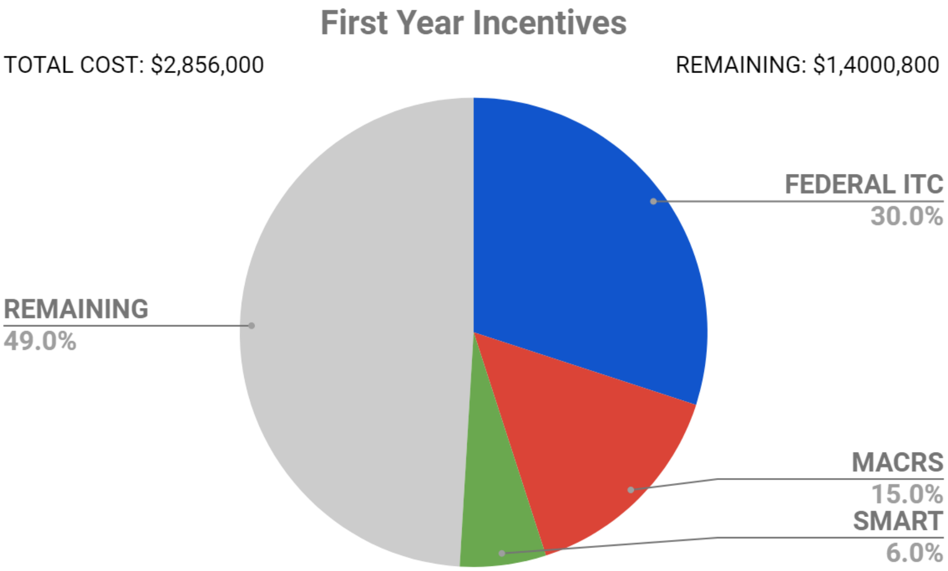
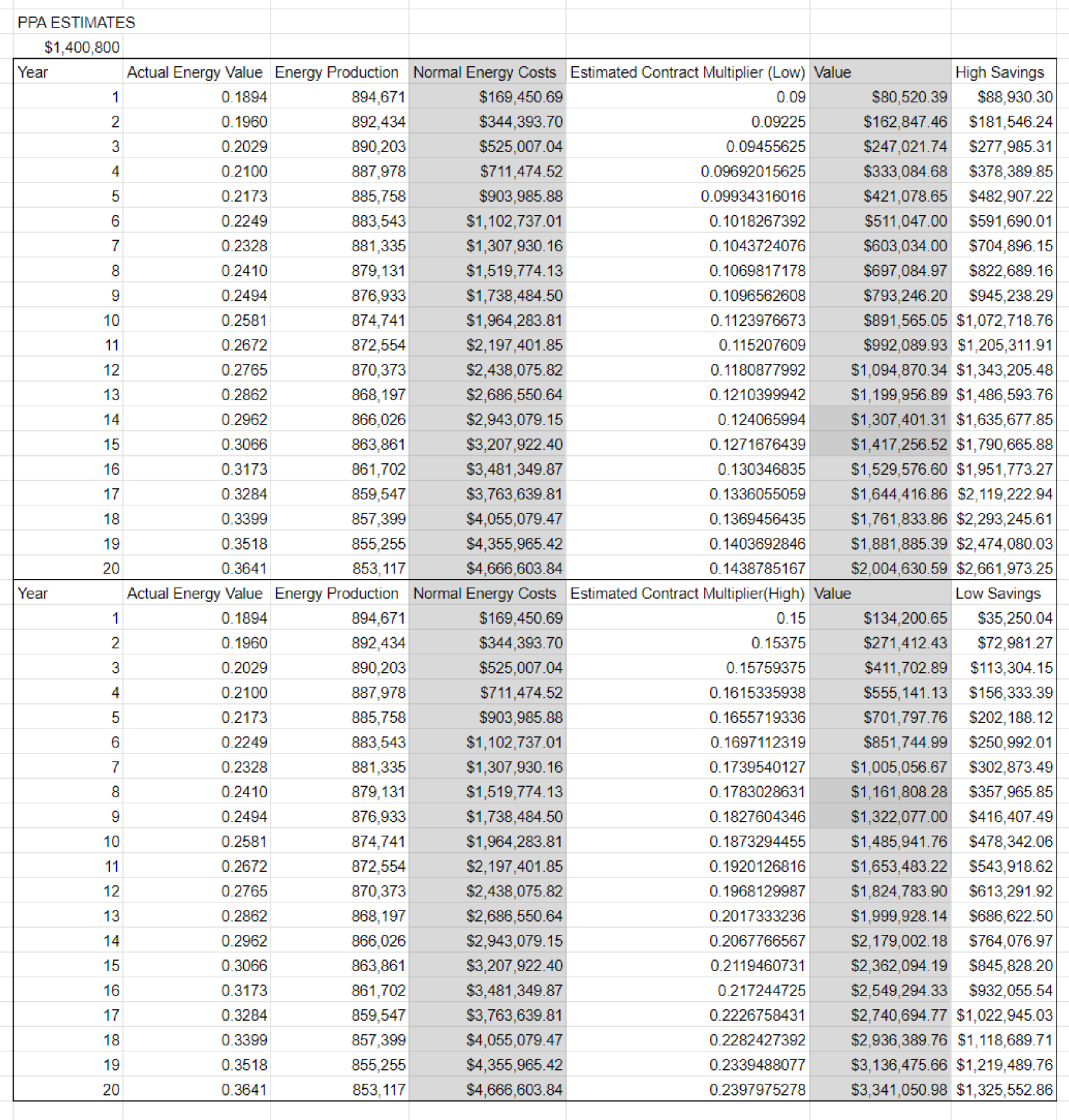


Figure D13 - First Year Incentives for North Lot T Support



PPA ESTIMATES

$1,400,800

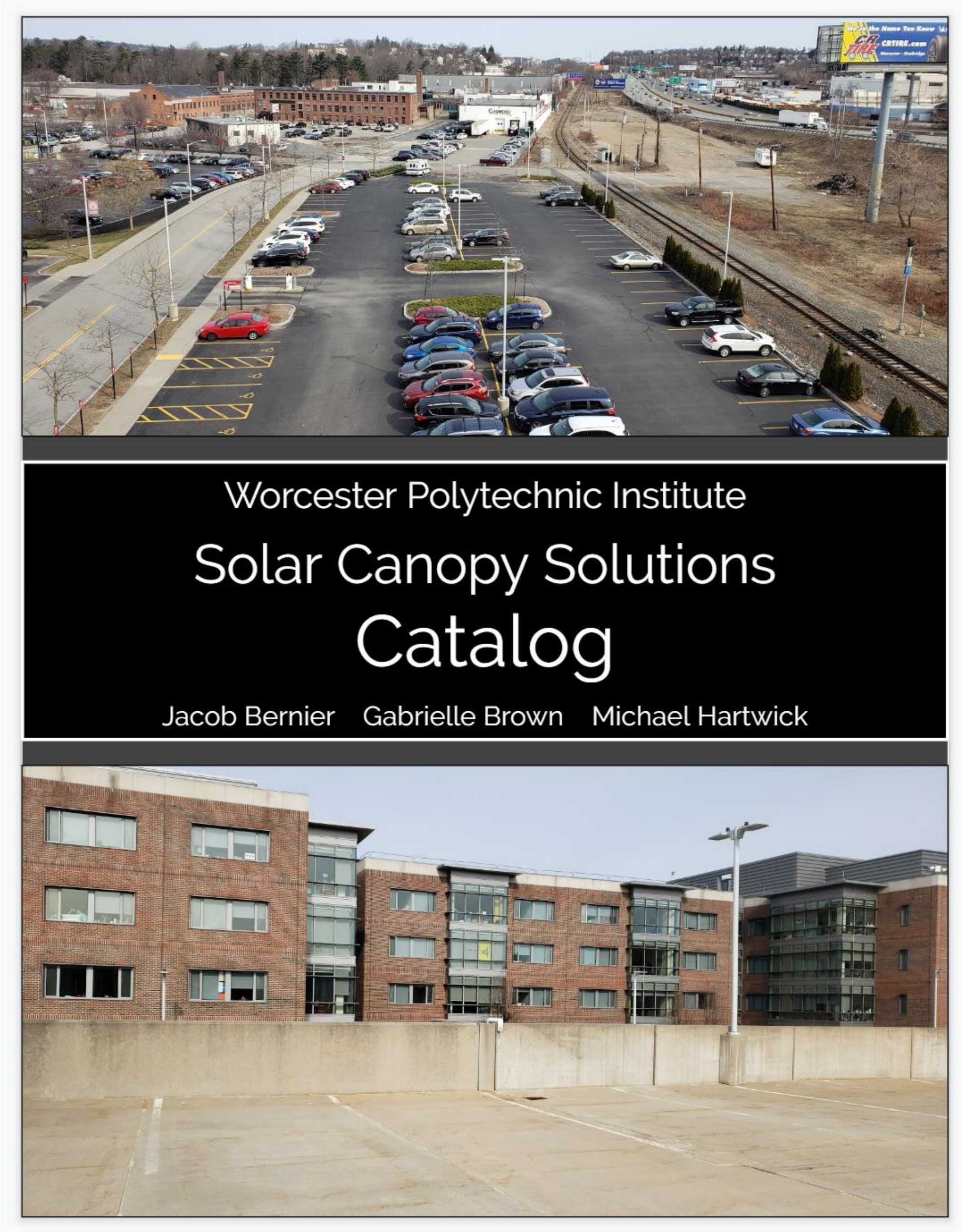
Year	Actual Energy Value	Energy Production	Normal Energy Costs	Estimated Contract Multiplier (Low)	Value	High Savings
1	0.1894	894,671	$169,450.69	0.09	$80,520.39	$88,930.30
2	0.1960	892,434	$344,393.70	0.09225	$162,847.46	$181,546.24
3	0.2029	890,203	$525,007.04	0.09455625	$247,021.74	$277,985.31
4	0.2100	887,978	$711,474.52	0.09692015625	$333,084.68	$378,389.85
5	0.2173	885,758	$903,985.88	0.09934316016	$421,078.65	$482,907.22
6	0.2249	883,543	$1,102,737.01	0.1018267392	$511,047.00	$591,690.01
7	0.2328	881,335	$1,307,930.16	0.1043724076	$603,034.00	$704,896.15
8	0.2410	879,131	$1,519,774.13	0.1069817178	$697,084.97	$822,689.16
9	0.2494	876,933	$1,738,484.50	0.1096562608	$793,246.20	$945,238.29
10	0.2581	874,741	$1,964,283.81	0.1123976673	$891,565.05	$1,072,718.76
11	0.2672	872,554	$2,197,401.85	0.115207609	$992,089.93	$1,205,311.91
12	0.2765	870,373	$2,438,075.82	0.1180877992	$1,094,870.34	$1,343,205.48
13	0.2862	868,197	$2,686,550.64	0.1210399942	$1,199,956.89	$1,486,593.76
14	0.2962	866,026	$2,943,079.15	0.124065994	$1,307,401.31	$1,635,677.85
15	0.3066	863,861	$3,207,922.40	0.1271676439	$1,417,256.52	$1,790,665.88
16	0.3173	861,702	$3,481,349.87	0.130346835	$1,529,576.60	$1,951,773.27
17	0.3284	859,547	$3,763,639.81	0.1336055059	$1,644,416.86	$2,119,222.94
18	0.3399	857,399	$4,055,079.47	0.1369456435	$1,761,833.86	$2,293,245.61
19	0.3518	855,255	$4,355,965.42	0.1403692846	$1,881,885.39	$2,474,080.03
20	0.3641	853,117	$4,666,603.84	0.1438785167	$2,004,630.59	$2,661,973.25

Year	Actual Energy Value	Energy Production	Normal Energy Costs	Estimated Contract Multiplier(High)	Value	Low Savings
1	0.1894	894,671	$169,450.69	0.15	$134,200.65	$35,250.04
2	0.1960	892,434	$344,393.70	0.15375	$271,412.43	$72,981.27
3	0.2029	890,203	$525,007.04	0.15759375	$411,702.89	$113,304.15
4	0.2100	887,978	$711,474.52	0.1615335938	$555,141.13	$156,333.39
5	0.2173	885,758	$903,985.88	0.1655719336	$701,797.76	$202,188.12
6	0.2249	883,543	$1,102,737.01	0.1697112319	$851,744.99	$250,992.01
7	0.2328	881,335	$1,307,930.16	0.1739540127	$1,005,056.67	$302,873.49
8	0.2410	879,131	$1,519,774.13	0.1783028631	$1,161,808.28	$357,965.85
9	0.2494	876,933	$1,738,484.50	0.1827604346	$1,322,077.00	$416,407.49
10	0.2581	874,741	$1,964,283.81	0.1873294455	$1,485,941.76	$478,342.06
11	0.2672	872,554	$2,197,401.85	0.1920126816	$1,653,483.22	$543,918.62
12	0.2765	870,373	$2,438,075.82	0.1968129987	$1,824,783.90	$613,291.92
13	0.2862	868,197	$2,686,550.64	0.2017333236	$1,999,928.14	$686,622.50
14	0.2962	866,026	$2,943,079.15	0.2067766567	$2,179,002.18	$764,076.97
15	0.3066	863,861	$3,207,922.40	0.2119460731	$2,362,094.19	$845,828.20
16	0.3173	861,702	$3,481,349.87	0.217244725	$2,549,294.33	$932,055.54
17	0.3284	859,547	$3,763,639.81	0.2226758431	$2,740,694.77	$1,022,945.03
18	0.3399	857,399	$4,055,079.47	0.2282427392	$2,936,389.76	$1,118,689.71
19	0.3518	855,255	$4,355,965.42	0.2339488077	$3,136,475.66	$1,219,489.76
20	0.3641	853,117	$4,666,603.84	0.2397975278	$3,341,050.98	$1,325,552.86

Figure D14 - PPA Estimates

Appendix E: Catalog

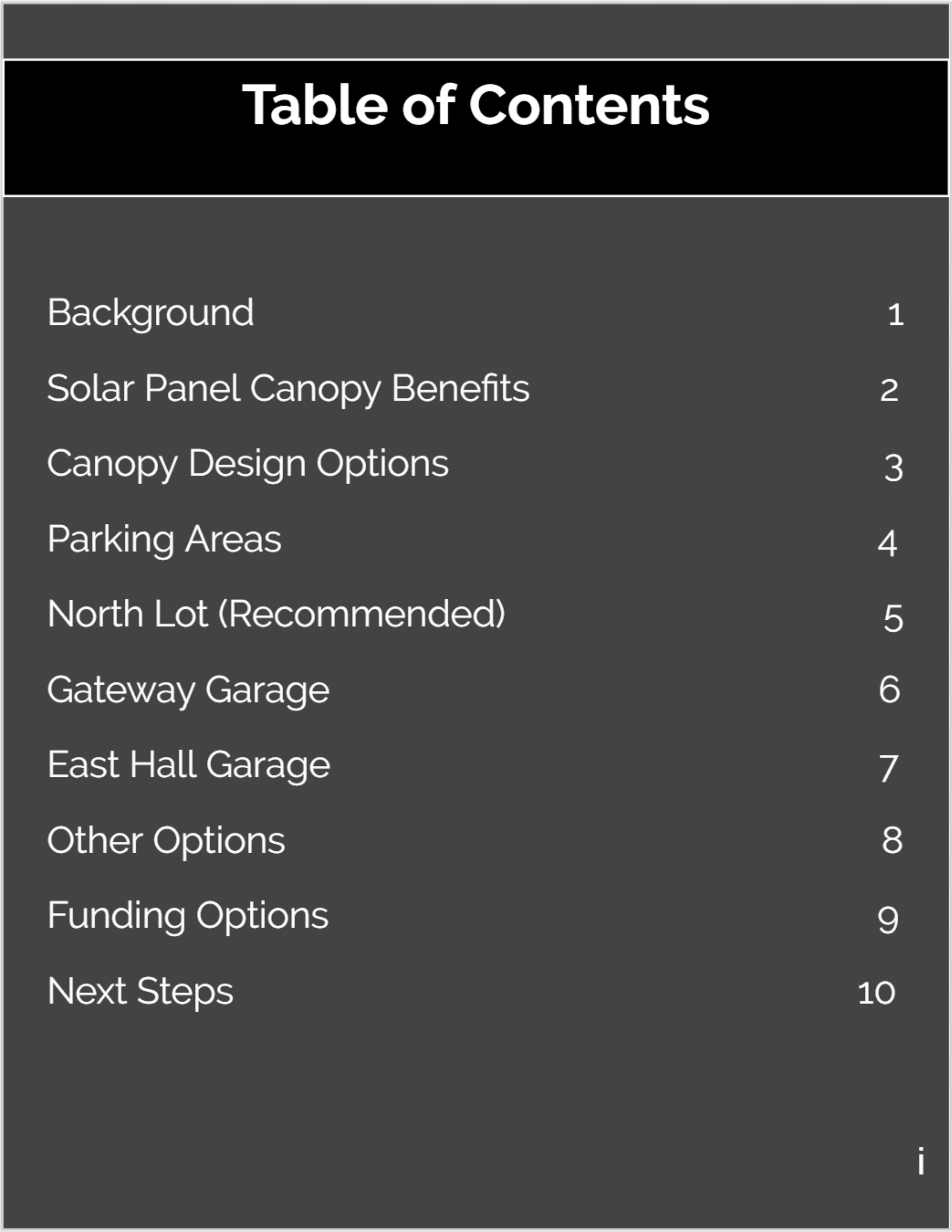
In addition to this report and our team's final presentation, a detailed catalog was also created to display different design and funding options as well as key background information in a concise and visual manner. This catalog is shown below.



Worcester Polytechnic Institute

Solar Canopy Solutions Catalog

Jacob Bernier Gabrielle Brown Michael Hartwick



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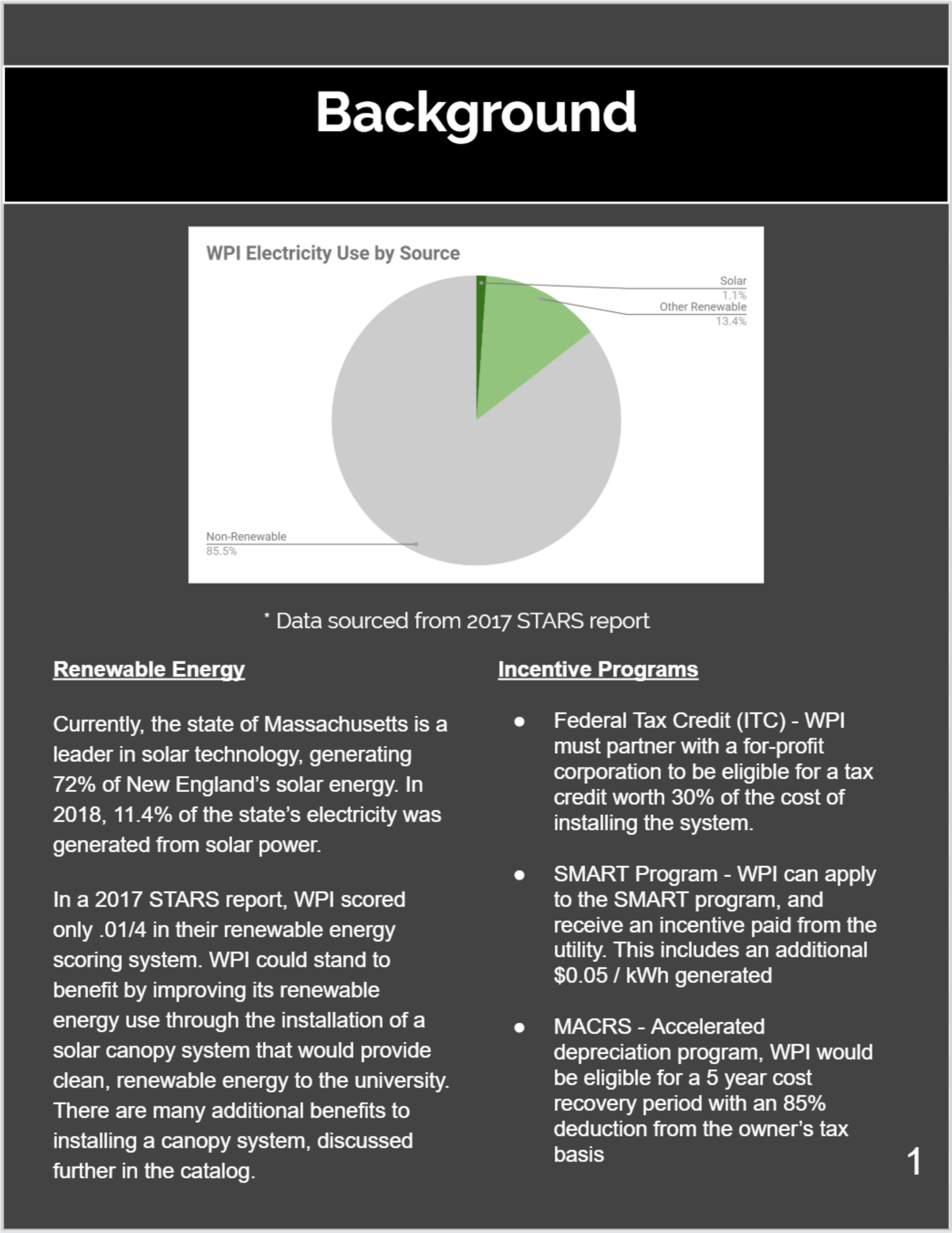


Background

* Data sourced from 2017 STARS report

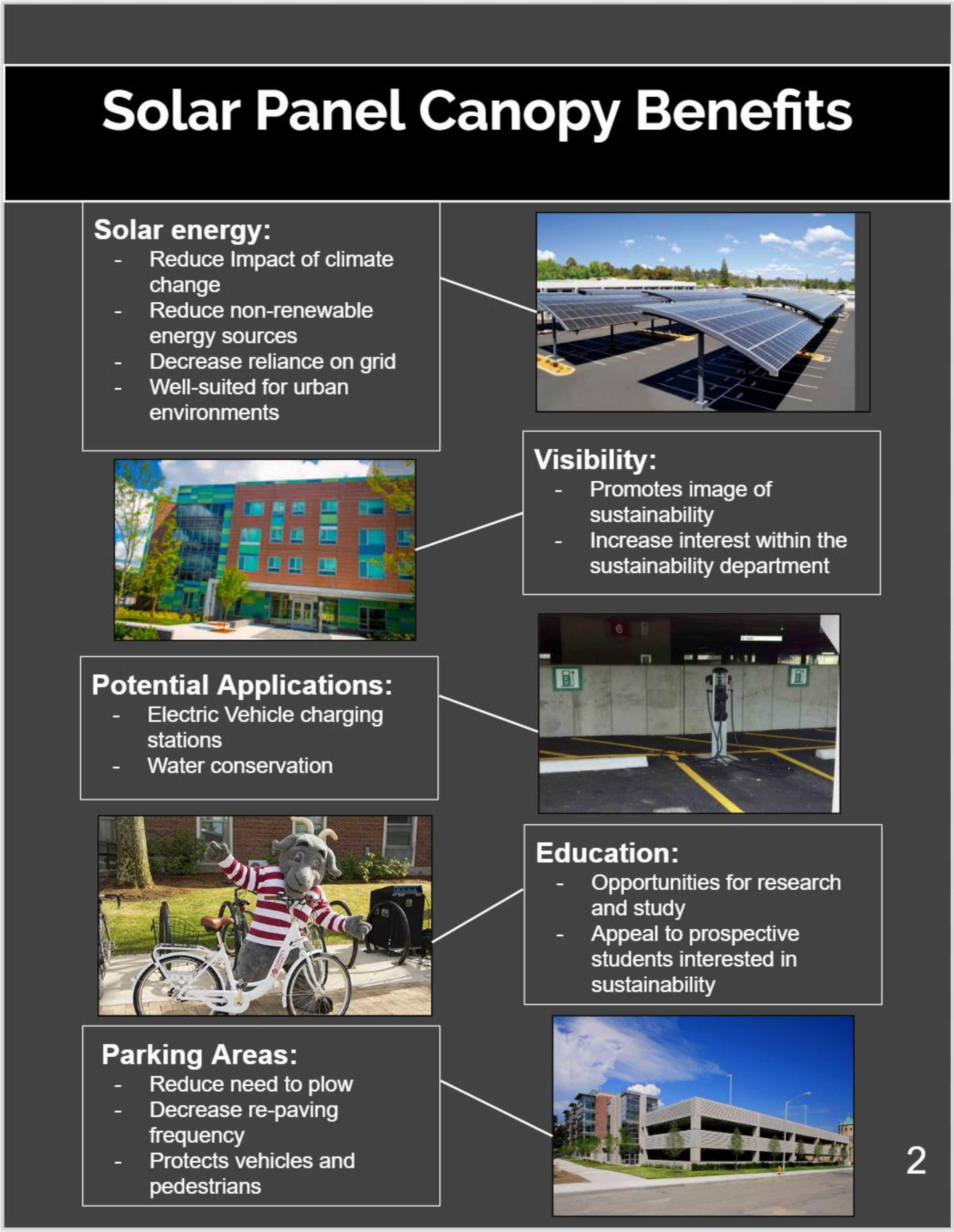
Renewable Energy

Currently, the state of Massachusetts is a leader in solar technology, generating 72% of New England's solar energy. In 2018, 11.4% of the state's electricity was generated from solar power.

In a 2017 STARS report, WPI scored only .01/4 in their renewable energy scoring system. WPI could stand to benefit by improving its renewable energy use through the installation of a solar canopy system that would provide clean, renewable energy to the university. There are many additional benefits to installing a canopy system, discussed further in the catalog.

Incentive Programs

- Federal Tax Credit (ITC) - WPI must partner with a for-profit corporation to be eligible for a tax credit worth 30% of the cost of installing the system.
- SMART Program - WPI can apply to the SMART program, and receive an incentive paid from the utility. This includes an additional $0.05 / kWh generated
- MACRS - Accelerated depreciation program, WPI would be eligible for a 5 year cost recovery period with an 85% deduction from the owner's tax basis



Solar Panel Canopy Benefits

Solar energy:

- Reduce Impact of climate change
- Reduce non-renewable energy sources
- Decrease reliance on grid
- Well-suited for urban environments

Visibility:

- Promotes image of sustainability
- Increase interest within the sustainability department

Potential Applications:

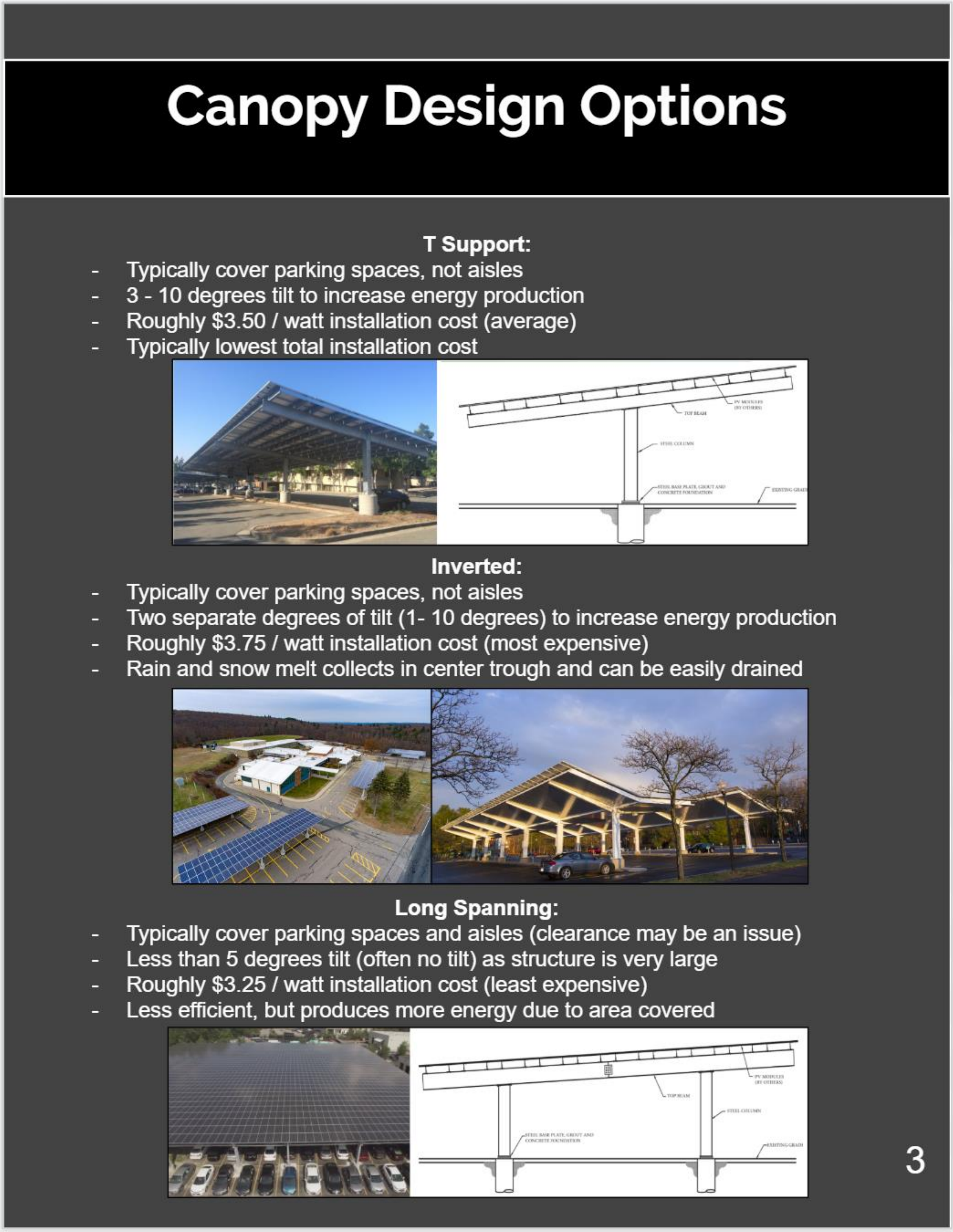
- Electric Vehicle charging stations
- Water conservation

Education:

- Opportunities for research and study
- Appeal to prospective students interested in sustainability

Parking Areas:

- Reduce need to plow
- Decrease re-paving frequency
- Protects vehicles and pedestrians



Canopy Design Options

T Support:

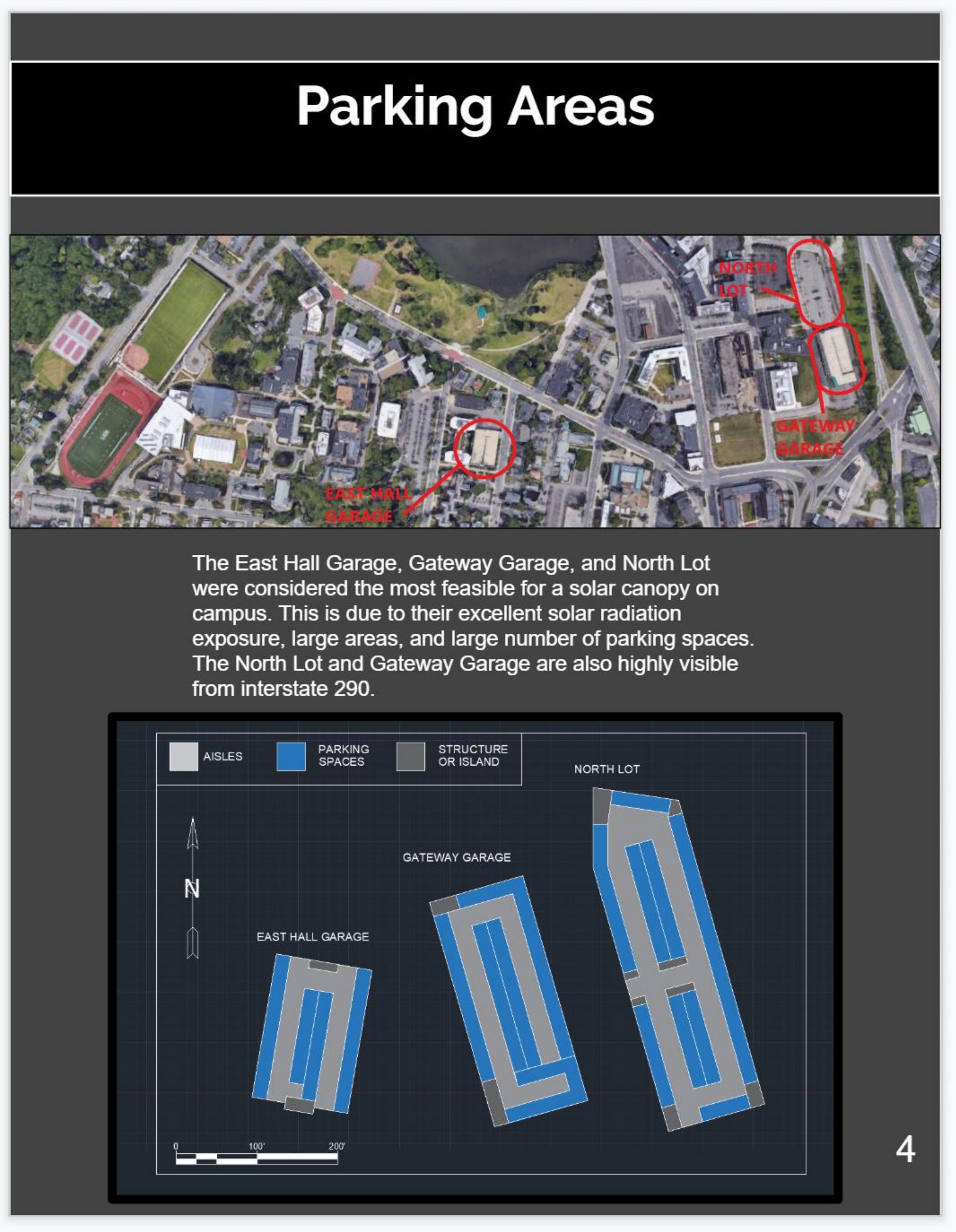
- Typically cover parking spaces, not aisles
- 3 - 10 degrees tilt to increase energy production
- Roughly $3.50 / watt installation cost (average)
- Typically lowest total installation cost

Inverted:

- Typically cover parking spaces, not aisles
- Two separate degrees of tilt (1- 10 degrees) to increase energy production
- Roughly $3.75 / watt installation cost (most expensive)
- Rain and snow melt collects in center trough and can be easily drained

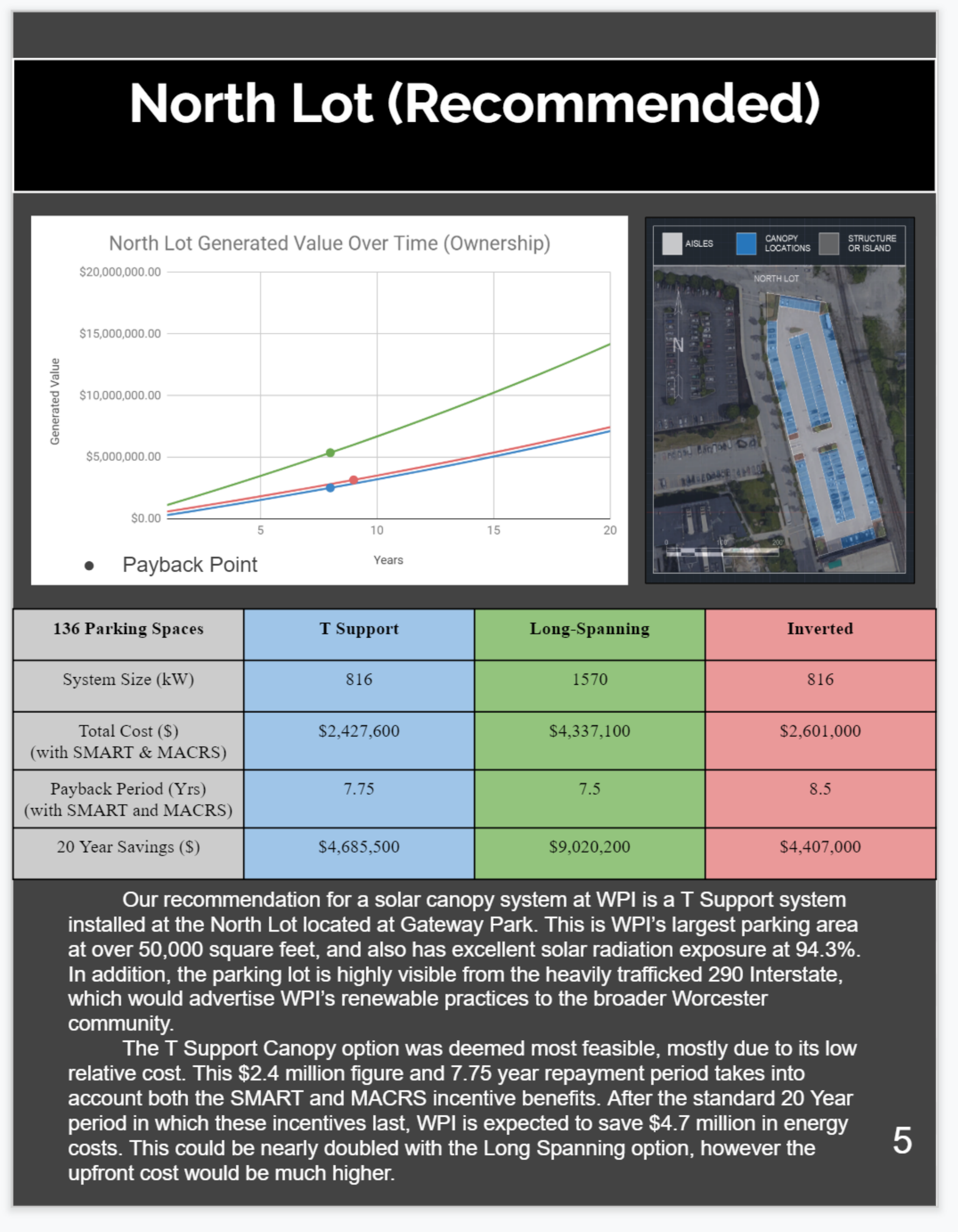
Long Spanning:

- Typically cover parking spaces and aisles (clearance may be an issue)
- Less than 5 degrees tilt (often no tilt) as structure is very large
- Roughly $3.25 / watt installation cost (least expensive)
- Less efficient, but produces more energy due to area covered



Parking Areas

The East Hall Garage, Gateway Garage, and North Lot were considered the most feasible for a solar canopy on campus. This is due to their excellent solar radiation exposure, large areas, and large number of parking spaces. The North Lot and Gateway Garage are also highly visible from interstate 290.

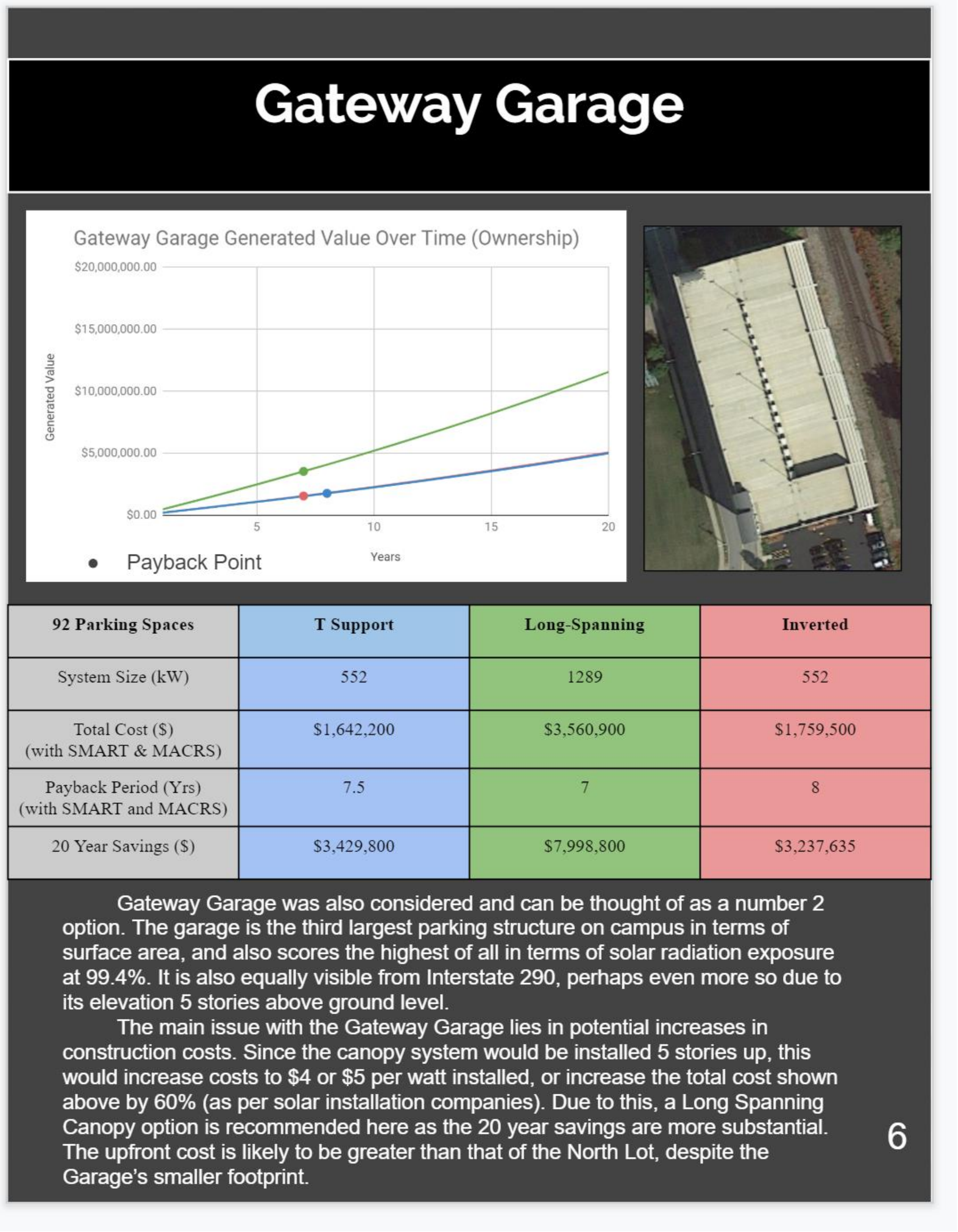


North Lot (Recommended)

136 Parking Spaces	T Support	Long-Spanning	Inverted
System Size (kW)	816	1570	816
Total Cost ($) (with SMART & MACRS)	$2,427,600	$4,337,100	$2,601,000
Payback Period (Yrs) (with SMART and MACRS)	7.75	7.5	8.5
20 Year Savings ($)	$4,685,500	$9,020,200	$4,407,000

Our recommendation for a solar canopy system at WPI is a T Support system installed at the North Lot located at Gateway Park. This is WPI's largest parking area at over 50,000 square feet, and also has excellent solar radiation exposure at 94.3%. In addition, the parking lot is highly visible from the heavily trafficked 290 Interstate, which would advertise WPI's renewable practices to the broader Worcester community.

The T Support Canopy option was deemed most feasible, mostly due to its low relative cost. This $2.4 million figure and 7.75 year repayment period takes into account both the SMART and MACRS incentive benefits. After the standard 20 Year period in which these incentives last, WPI is expected to save $4.7 million in energy costs. This could be nearly doubled with the Long Spanning option, however the upfront cost would be much higher.

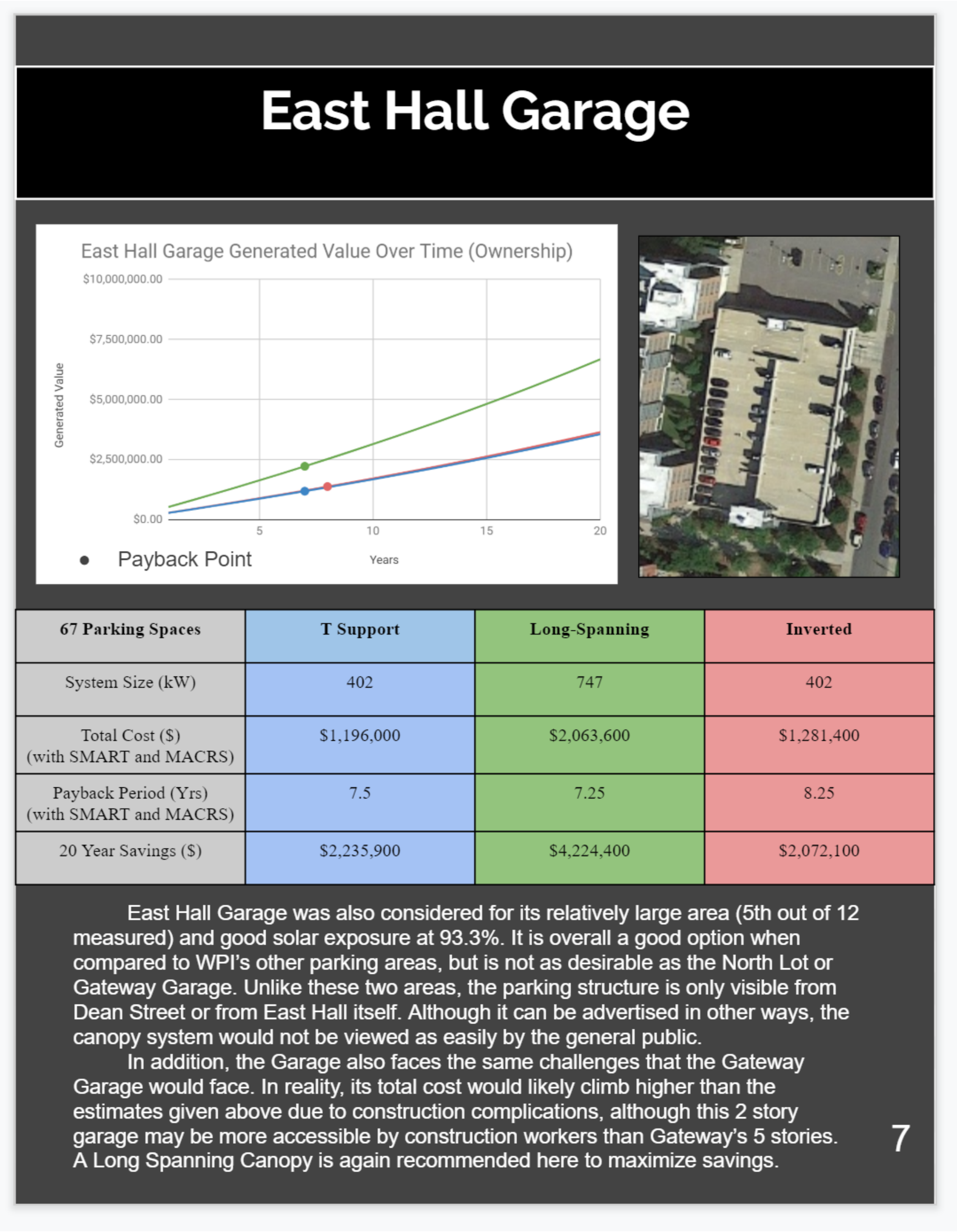


Gateway Garage

92 Parking Spaces	T Support	Long-Spanning	Inverted
System Size (kW)	552	1289	552
Total Cost ($) (with SMART & MACRS)	$1,642,200	$3,560,900	$1,759,500
Payback Period (Yrs) (with SMART and MACRS)	7.5	7	8
20 Year Savings ($)	$3,429,800	$7,998,800	$3,237,635

Gateway Garage was also considered and can be thought of as a number 2 option. The garage is the third largest parking structure on campus in terms of surface area, and also scores the highest of all in terms of solar radiation exposure at 99.4%. It is also equally visible from Interstate 290, perhaps even more so due to its elevation 5 stories above ground level.

The main issue with the Gateway Garage lies in potential increases in construction costs. Since the canopy system would be installed 5 stories up, this would increase costs to $4 or $5 per watt installed, or increase the total cost shown above by 60% (as per solar installation companies). Due to this, a Long Spanning Canopy option is recommended here as the 20 year savings are more substantial. The upfront cost is likely to be greater than that of the North Lot, despite the Garage's smaller footprint.

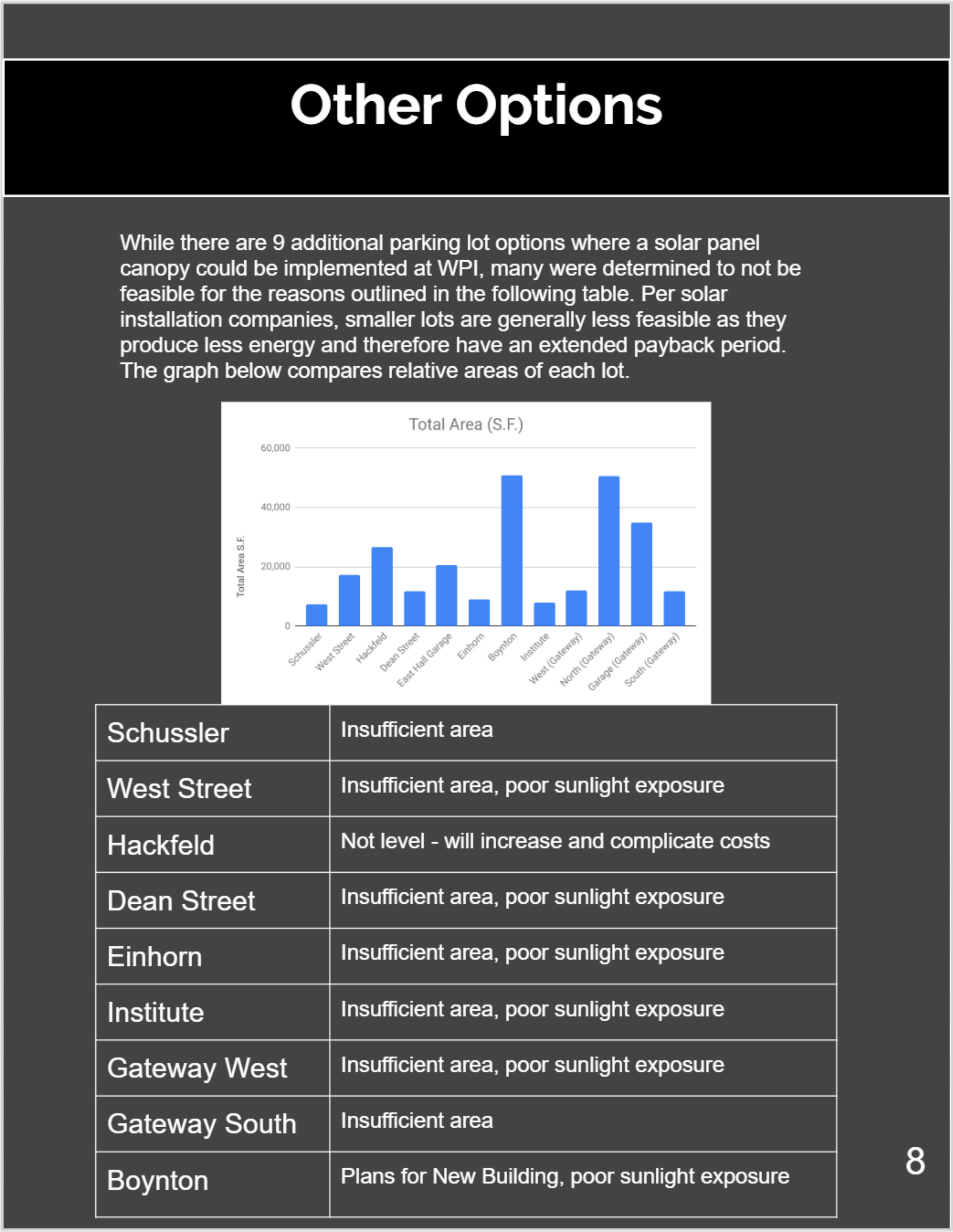


East Hall Garage

67 Parking Spaces	**T Support**	**Long-Spanning**	**Inverted**
System Size (kW)	402	747	402
Total Cost ($) (with SMART and MACRS)	$1,196,000	$2,063,600	$1,281,400
Payback Period (Yrs) (with SMART and MACRS)	7.5	7.25	8.25
20 Year Savings ($)	$2,235,900	$4,224,400	$2,072,100

East Hall Garage was also considered for its relatively large area (5th out of 12 measured) and good solar exposure at 93.3%. It is overall a good option when compared to WPI's other parking areas, but is not as desirable as the North Lot or Gateway Garage. Unlike these two areas, the parking structure is only visible from Dean Street or from East Hall itself. Although it can be advertised in other ways, the canopy system would not be viewed as easily by the general public.

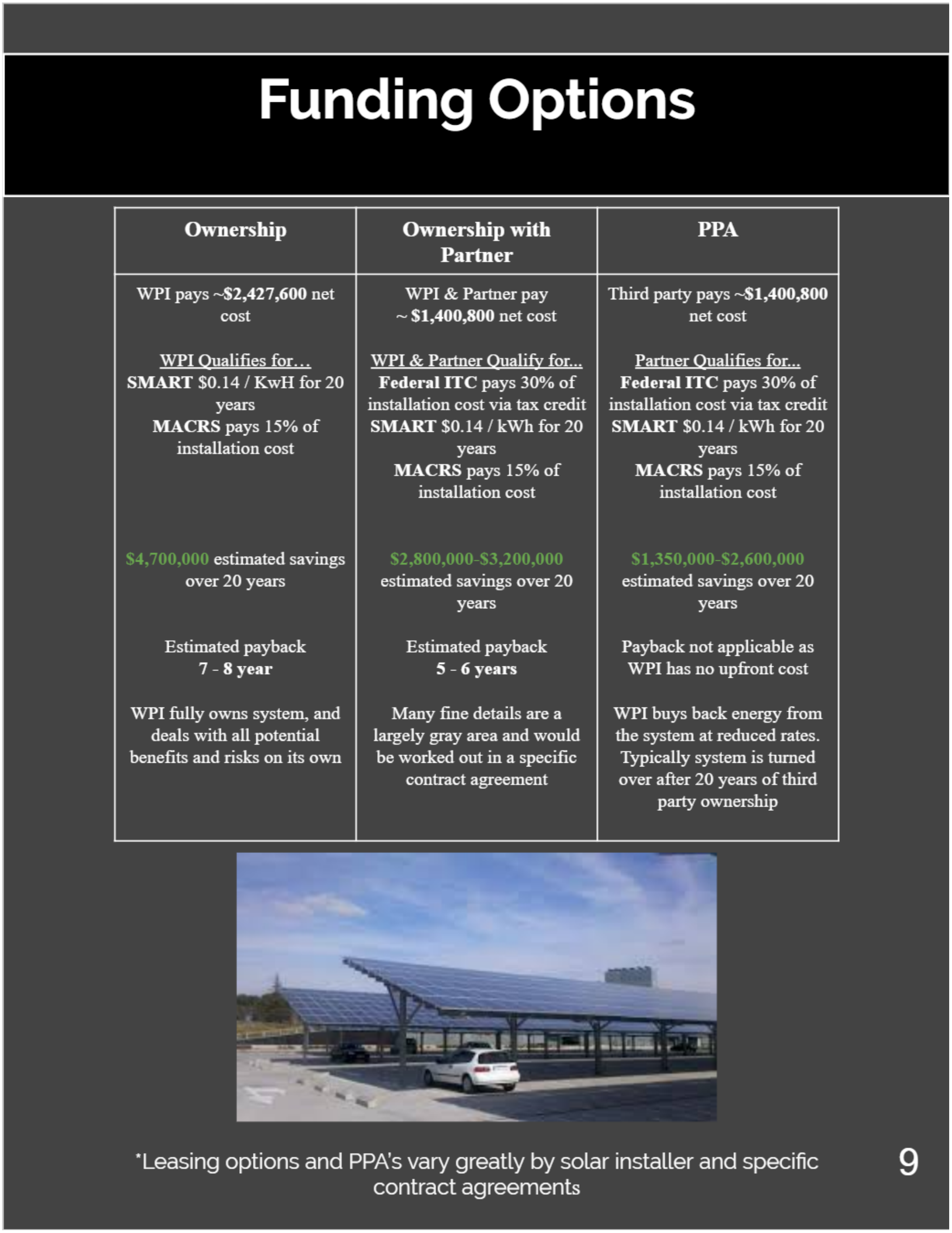
In addition, the Garage also faces the same challenges that the Gateway Garage would face. In reality, its total cost would likely climb higher than the estimates given above due to construction complications, although this 2 story garage may be more accessible by construction workers than Gateway's 5 stories. A Long Spanning Canopy is again recommended here to maximize savings.



Other Options

While there are 9 additional parking lot options where a solar panel canopy could be implemented at WPI, many were determined to not be feasible for the reasons outlined in the following table. Per solar installation companies, smaller lots are generally less feasible as they produce less energy and therefore have an extended payback period. The graph below compares relative areas of each lot.

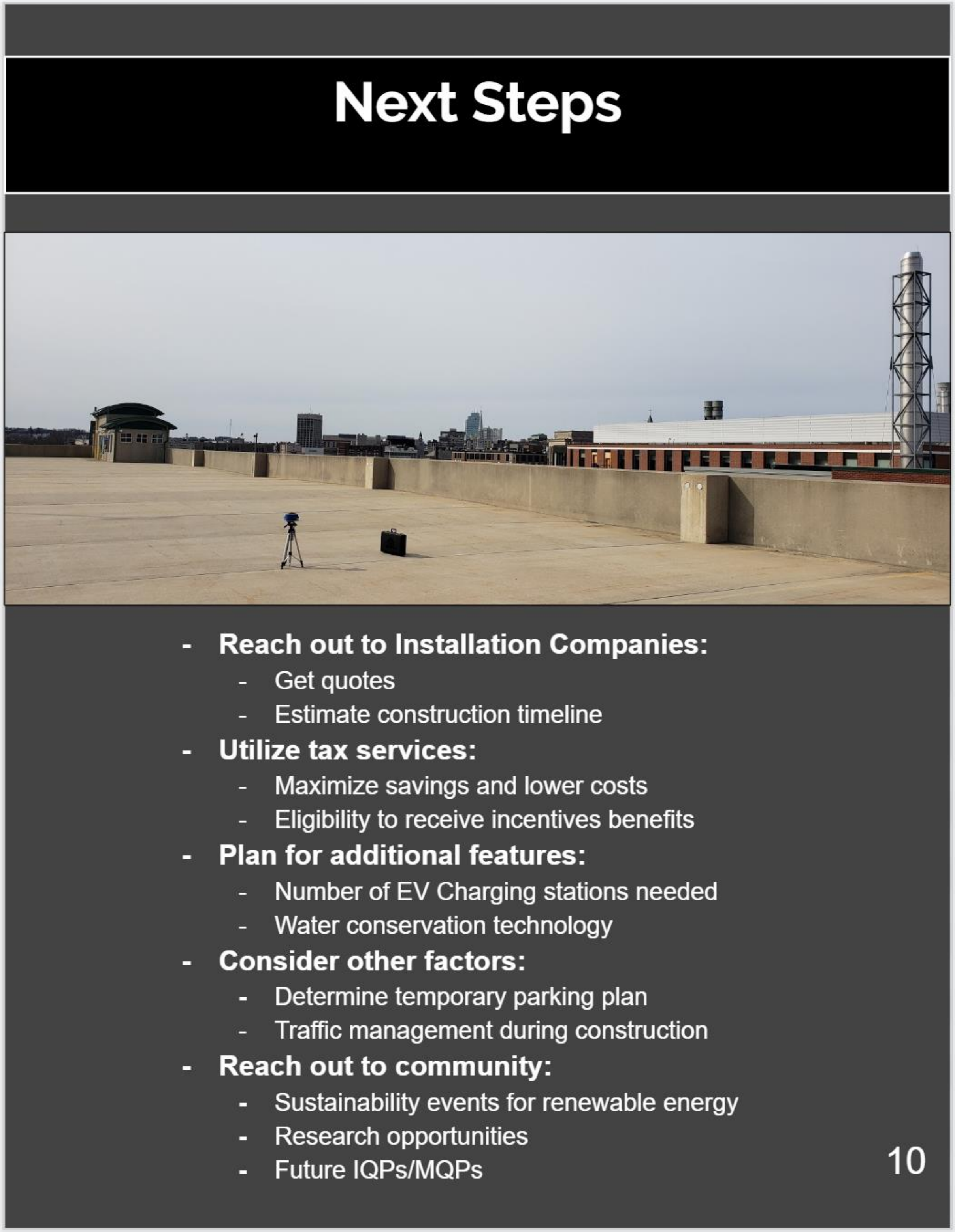
Schussler	Insufficient area
West Street	Insufficient area, poor sunlight exposure
Hackfeld	Not level - will increase and complicate costs
Dean Street	Insufficient area, poor sunlight exposure
Einhorn	Insufficient area, poor sunlight exposure
Institute	Insufficient area, poor sunlight exposure
Gateway West	Insufficient area, poor sunlight exposure
Gateway South	Insufficient area
Boynton	Plans for New Building, poor sunlight exposure



Funding Options

Ownership	Ownership with Partner	PPA
WPI pays ~**$2,427,600** net cost	WPI & Partner pay ~ **$1,400,800** net cost	Third party pays ~**$1,400,800** net cost
WPI Qualifies for… **SMART** $0.14 / KwH for 20 years **MACRS** pays 15% of installation cost	WPI & Partner Qualify for... **Federal ITC** pays 30% of installation cost via tax credit **SMART** $0.14 / kWh for 20 years **MACRS** pays 15% of installation cost	Partner Qualifies for... **Federal ITC** pays 30% of installation cost via tax credit **SMART** $0.14 / kWh for 20 years **MACRS** pays 15% of installation cost
$4,700,000 estimated savings over 20 years	$2,800,000-$3,200,000 estimated savings over 20 years	$1,350,000-$2,600,000 estimated savings over 20 years
Estimated payback 7 - **8 year**	Estimated payback **5** - **6 years**	Payback not applicable as WPI has no upfront cost
WPI fully owns system, and deals with all potential benefits and risks on its own	Many fine details are a largely gray area and would be worked out in a specific contract agreement	WPI buys back energy from the system at reduced rates. Typically system is turned over after 20 years of third party ownership

*Leasing options and PPA's vary greatly by solar installer and specific contract agreements



Next Steps

- **Reach out to Installation Companies:**
  - Get quotes
  - Estimate construction timeline
- **Utilize tax services:**
  - Maximize savings and lower costs
  - Eligibility to receive incentives benefits
- **Plan for additional features:**
  - Number of EV Charging stations needed
  - Water conservation technology
- **Consider other factors:**
  - Determine temporary parking plan
  - Traffic management during construction
- **Reach out to community:**
  - Sustainability events for renewable energy
  - Research opportunities
  - Future IQPs/MQPs

Appendix F: Interviews

Informal Interview with Mr. James Dunn, 26 March 2019 @ 0800:

Questions:

1. Can you tell us about how you became interested in solar energy?
2. Can you tell us about you background as it relates to your career path in renewable energy?
3. What is your experience with solar panel canopies?
4. What is your opinion of solar panel canopies in a lot, as compared to the top of a parking garage?
5. Is there a specific type of panel that you would recommend for the implementation of such a system?
6. What suggestions do you have for us moving forward with this project?
7. Is there anything else important you would like to add that we didn't ask or talk about?

We first spoke informally with Mr. Jim Dunn, a WPI alumnus, and an expert in the field of solar energy. Professor Looft referred us to speaking with Mr.Dunn and was also present at the interview. He gave us his professional opinion regarding solar panel canopies on college campuses, as well as general guidance as to the direction of our project. Mr. Dunn expressed that solar panels are not typically economically feasible and are usually more of a statement of sustainability. Mr. Dunn mentioned how we could look into alumni donations to help with cost. We kept this in mind for future interviews with solar panel companies when we discussed factors including upfront costs and return on investment. We assessed his opinion of our project and discussed solar energy use in Massachusetts, and at WPI specifically. He believes a solar panel canopy and a carport to be different, with carports having many potential issues. Mr. Dunn voiced concern with the climate and amount of snow received. This causes a liability for cars pulling into or backing out of the carport if the snow has not been removed. His interest in electric cars gave us a new perspective of what a solar panel canopy could power.

Mr. Dunn also challenged our perspective as to the economic benefits of solar, as he expressed his belief that canopies are not economically feasible in terms of return on investment. Rather, he believes that many of the projects have a social benefit, and that it is more important than cost for colleges to look sustainable. He related this to the difference in the culture surrounding renewable and solar energy on the East coast versus the West. We covered different types of panels, to which Mr. Dunn elaborated on his support for LG panels, which he liked the warranty policy for. He suggested for to us to go around and visit a few different sites with solar panel canopies. As far as eventually getting a project approved, Mr. Dunn informed us of alumni donations, and to begin speaking with members of the administration as soon as possible. We are now looking into possibly going to Stonehill to look at their panels. He was a valuable resource as far as his knowledge of solar energy. Mr. Dunn asked about our plans as far as a survey was concerned, to which we are considering looking into again to see how individuals might feel parking under a canopy.

Concluding the informal interview, Mr. Dunn told us to reach out again if had any questions or wanted to talk. We compiled our notes and plan to reference them as needed. This interview helped us to define our goals and allowed us to realize that there might not be a feasible option for WPI.

Interview with Solect Energy, 28 March 2019 @ 1300:

Questions:

1. Could you begin by telling us a little about the company and what types of projects you do?
2. What are some larger projects you’ve taken on before? Have you ever installed a solar panel canopy? Solar panels over a parking garage?
3. Based on these specs (list), what would you be able to provide a rough estimate, based on past projects (mention areas)
4. Do any of the aforementioned locations sound more feasible for construction and long term placement?
5. Is there a timeline for about how long such a project would take to complete?
6. Is there a warranty policy?
7. How long will the solar panels last?
8. Can you provide us with an information are far as maintenance that would be required?

9. Is there anything we should take into account as far as safety or insurance is concerned during and after construction?
10. Do you have any suggestions for us to make a proposal to our administration?
11. Is there anything else important you would like to add that we didn’t ask or talk about?
12. What factors are considered in picking a site for a solar canopy?
13. Does your company install the support structure as well or just the panels?
14. Do you use a solar pathfinder when analyzing a site? How many reference points do you use? Do you aim for 100% radiation exposure?
15. What are some general rules for estimating costs in a typical solar canopy project?
16. Would you be able to provide a rough estimate on installation costs based on the following data?

Lot Description	Area (square feet)	% Annual Radiation
5 Floor Parking Garage (Gateway Garage)	34,800	99.8%
2 Floor Parking Garage (East Hall)	20,160	99.5%
Large Open Parking Lot (North Lot)	50,660	95.3%

This company has been installing solar panels in Massachusetts for the last 10 years with both commercial and industrial clients. They focused on projects with panels on rooftops, but have completed a handfuls of canopies, with more in progress. They are currently completing some projects in the Worcester area, a 35 mw rooftop project and some other 50-70 kw rooftops. They provide both installation and support in Massachusetts, having done 20% of rooftop projects, while also servicing other projects. They have completed 450 projects to date, including some at Harvard. They also complete projects at car dealerships.

The representative explained that WPI will face certain challenges. Many of the incentives have been used up due to the National Grid in Worcester. National Grid overloaded stations are currently being studied, however, interconnection cannot get approved until the studies have been finished. This would ultimately cause any project that would normally take about 4-6 months to not be completed for 12-14 months. The representative mentioned that rooftop projects typically take about 8-12 weeks, because the support structure is not required as it is with a canopy design. There are 3 tiers of panel efficiencies: standard efficiency, high efficiency, and super high efficiency. For a canopy project, high efficiency panels at 390-400 watts are all that is needed. They are more cost efficient at about 4-5 cents/watt. The super high efficiency panel is typically about another 50 cents/watt. The tier is determined by market, and is not an industry rated standard. This allows for flexibility in cost, as often the investors will not know until availability until the time of purchase. Many solar panels are now made in the United States

This company includes maintenance as a part of the associate costs and is included in the quote provided. It is more costly to self maintain the canopy system because the equipment must be either purchased or rented. Warranties are also available. There is a 1 year full coverage warranty only if proper maintenance is adhered to. The company that makes the solar panels offers a 10-12 year manufacturer's warranty and an estimated 25 year output for the panel.
The representative suggested that to avoid losing out on warranties, WPI would need to document all maintenance. Technical reccommissions must be performed periodically to check specific safety standards and document it.

As far as location is concerned, the sunniest spot is the most ideal. Canopies oriented towards the South with an East/West dimension and at a 3-5% pitch is recommended by this company to help maximize energy produced. We learned that we can also look into judging cost and space by the number of parking spaces present. Furthermore, we should avoid parking lots that are sloped because the build will be more costly. Smaller lots, contrary to what we had thought before, are also more expensive. This is due to greater cost/watt and other challenges of installation in a smaller lot. One key point we learned is that canopies are designed to optimize energy produced, it isn't going to be perfect. They also offer a deal where the company owns the canopy and could sell the power to WPI, which would still provide the publicity associated with having a canopy on campus, but there would be no upfront cost to implement.

Other factors we might want to consider include water management. Water management, according to the representative, can be one of the biggest expenses. It would cover the lots from weather, however it would be a significant cost due to increased maintenance requirements. This is optional for panels. It either has to be 100% watertight or the water will need to drain off, it cannot be only part of the system. T design vs Inverted design was also mentioned, and the design depends on the location chosen for what would work best.

The interview concluded with the representative offering to send us a calculator for costs and encouraging us to reach out if we had any additional questions. We sent a follow up email confirming we had received the calculator and thanking them for their time.

Interview with ReVision Energy, 10 April 2019 @ 1600:

An interview with a second solar panel company helped us to further support our own data collection and gave us an idea of potential variability between companies. It is an employee-owned company that services Maine, New Hampshire, and Massachusetts. They are capable of installing and servicing panels for residences, businesses, and other commercial locations. Their claim as an industry leader for factors including the design, installation, and maintenance. They believe in achieving a high level of safety and technical standards. Customer satisfaction is an important component of their philosophy.

Projects have included solar energy systems that range from 8 - 6,250 panels (2 megawatts). They also supply the associated storage. Other projects related to renewable energy include air source heaters and charging stations for electric vehicles. They have installed multiple projects, including many multi-megawatt systems. One of their projects involved a solar system over a capped landfill. They have previously installed two canopy systems over parking garages and another over a lot.

The factor of cost can be summarized with 3 dollars/watt as a general rule, but can increase to 4-5 dollars/watt. Price can also be affected by accessibility to the location to build. It is not taxable, and is not eligible for the 30% tax credit. The typical payback period for a solar panel canopy is about 10 years.

Factors that are important for location includes a south facing orientation. It would also be beneficial if it could be close to a source of electricity to avoid digging unnecessarily to transfer the power generated. A larger area is more advantageous due to the scale of energy that can be produced, and referenced the concept of economies of scale. When analyzing a site, this company uses LiDAR. LiDAR stands for Light Detection and Ranging. It is unrealistic to aim for 100% solar radiation exposure, and there is no perfect location. Often, if the radiation exposure is greater than 80%, it can be considered adequate. Canopies are complicated and actually need to gain better exposure over time for it to be worth the money. This is where incentives such as the SMART program can assist.

Their answer for a timeline for installation was very similar to that of the company previously interviewed. It depends on a variety of factors, however, due to the study being completed in Worcester currently, it is not ideal. The study is looking at utility impacts. It is being completed by National Grid who is currently looking at the infrastructure in place and how it can be updated with respect to distribution and transmission and is projected to last about 12 months. After completion of the study, installation would take about 3 months to design and implement the canopy system.

As far as warranties are concerned, this company offers a 5 year workmanship warranty. They will also take care of any warranties extended to the purchaser by the manufacturer. Most panels come with a 25 year warranty. Inverters are often warrantied for a period of 10-12 years. Though Solar panels are warrantied for 25 years, they can still produce energy 40 years after installation. Theoretically, solar panels only lose 5-7% of productivity after 25 years, and should be warrantied if they lose 10+% during that time. At that point, however, technology will have advanced to the point where they will most likely have been replaced due to a want for higher efficiency and more energy produced.

This company carries insurance throughout the construction period. This would later be transferred as a main responsibility of the institution or residence who will own the system. The representative looking into ways to supplement a basic insurance policy for extended coverage. The canopies are expensive, and having decent insurance is an important factor.

Maintenance required involves an inspection of the entire system once a year. According to the representative, besides snow removal, most other maintenance that might be necessary is typically nominal such as tree and shrub control and animals making nests in the structure. Because the panels are stationary and there are no fluids involved, routine maintenance as a whole is not as involved as one might suppose.

As far as making a proposal to our administration, the representative suggested we are well versed in the economics surrounding the project. There are many benefits the representative encouraged us to bring up in our proposal, which are summarized below. We should be looking to highlight the benefits such as combating climate change. Some prospective students choose schools based on sustainable practices, for which this could increase interest in WPI. Though snow would need to be removed from the structure on occasion, it would also reduce the need for plowing as well as reducing the frequency of needing to repave the lot. It keeps cars protected and could also be adapted into a charging station for electric vehicles. Solar canopies are very space conscious for urban environments. Furthermore, the visibility and promotion of WPI as a sustainable institution would be positive publicity.

We concluded the interview by thanking the representative for their time and compiled the notes taken from the phone interview and the information that was sent to us.

Interview with Stonehill College Director of Sustainability, Ms. Jessa Gagne via Email:

Questions:

1. Can you elaborate on the process it took for the project to be approved? How long was it?
2. Can you tell us about the current system you have in place with the solar panels :
    a. How many
    b. Area covered
    c. Energy generated
    d. What it powers
    e. Current upkeep/maintenance required-- associated costs
3. Can you elaborate on power purchase agreements?
4. Would you be able to disclose approximately how much was spent on the solar panels?
5. Was the return on investment what was expected?
6. Do you find that the panels are well received by the campus and surrounding community?
7. How do you use the panels to further promote sustainable practices?
8. Have you encountered any issues with students or staff not wanting to park under the canopy?
9. Is there anything else important you would like to add that we didn’t ask or talk about?

After communication over email, Ms. Gagne sent us a PowerPoint that contained the information that Stonehill College had used to make the argument for why solar was needed on their campus and its implementation. It was 16 slides, 5 of which were pictures.

Part of the project’s approval was due to them working with a coordinator to help ensure that they were receiving all the benefits they were eligible for. It mentioned that nonprofit organizations cannot use tax credits. The project was funded through a Power Purchase Agreement (PPA), where the company will construct, own, and maintain the system and the institution buys the power generated.

PPAs involve a locked-in cost in kilowatt hours, accounting for the change in years. The rate is competitive and predictable. There is also a full warranty on the canopy system. Other costs that needed to be considered included relocation lighting and cameras, related infrastructure required, police details, and finding new areas for parking during construction. These were factors that would need to be paid for by Stonehill.

Furthermore there are both pros and cons to erecting such a structure, many of which were not economically related. Some drawbacks include that it is pretty permanent, and would be a 15-20 year commitment. You also need to rely heavily on the installation company to ensure maintenance. Furthermore, contracts are not set until construction is initiated, and changes could pose a potential risk to the institution. The number of parking spaces would also be reduced. Many other risks mentioned were specific to the area Stonehill was proposing to install the canopy, an issue WPI would also run into, depending on the location. Benefits included lessening energy and maintenance costs (with a PPA). The canopy would aid the grid by reducing the amount of energy drawn from it. There are larger environmental impacts such as the reduction of climate change through producing less greenhouse gas. Property value improves. One major benefit of using a PPA is that charging stations for electric vehicles can be installed at no additional cost.

There are also economic reasons to opt for a solar panel canopy. Factors such as Production Income and Net Metering. Production Income occurs when the amount of energy obtained from a utility is decreased by the same amount of energy being produced by the canopy system. Net Metering is applicable for when more energy is generated than what is needed and can be applied elsewhere. There are incentives at both the State and Federal Level. While many Stonehill College used are no longer applicable, WPI could look into other, newer incentive programs, such as SMART.

Though Stonehill used a PPA to fund the canopy, there were other financing options considered. The option of leasing was discussed, as a fixed payment is an expense that could be deducted. With a lease, there is a possibility that there will be additional extra payments at the end of the agreed upon term. Energy costs are still at an expected rate. The canopy could also be purchased outright and owned. There are some financial benefits that included avoiding electrical costs. The return on investment was also the best with this option.

There were further considerations that were taken into account regarding the specifications of the structure. The support structure, potential obstructions, the orientation, and exposure to sunlight, access to the grid, and overall impact of the space. As far as utilizing the electricity, Stonehill College would need to think about the transformer's performance in terms of its age, capacity, and its location. They needed an understanding of how the system they had in place would be adapted to accommodate for the canopy.

Stonehill was very interested in Solar and had phases for different projects they planned to install and determined the size of each system. They calculated how much energy they could produce and compared it to how much they use, and found that the collective systems could provide up to 44% of the energy needed.

We thanked Ms. Gagne for the information and after the interview had a much better understanding of purchasing options as well as the extent of the planning that goes into such a project.

Interview with WPI Director of Sustainability, Dr. Paul Mathisen, 09 April 2019 @ 0900:

Questions:

1. Can you elaborate on how solar energy might fit in with the new WPI Sustainability Plan?
2. Do you think a solar panel canopy would be a feasible in one of the parking lots (give example of North Lot)? Parking garage (East/Gateway)?
3. How could we use our IQP to promote sustainability on campus and engage students and staff? How could the implementation of the project engage the community?
4. Is there a location you believe would be best based solely on publicity?
5. How have similar past projects been successful in making proposals or recommendations and gaining support?

6. Based on past projects you have seen, how do you think the WPI community would react to the project proposal?
7. We are looking to make a proposal or recommendation to someone in administration about the most feasible options for a solar canopy, is there an individual or a group of people we should look to speak to?
8. Is there anything else important you would like to add that we didn't ask or talk about?

The informal interview with Dr. Mathisen was helpful as it initiated a deeper understanding of how our project might be approved. He referred us to speaking with Ds. Elizabeth Tomaszewski, the Associate Director of Sustainability. Due to her connection to facilities and construction, he believed she would be more helpful to our project.

He believed the element of cost to be the most important, and did not personally think a payback period of 12 years was unreasonable. Though Dr. Mathisen then reminded us that WPI is a very fiscally conservative institution. He mentioned a previous project that involved a demo of a few panels that would have been funded by the green revolving fund. He also expressed that there was definite interest in implementing a solar panel canopy on campus. Dr. Mathisen was concerned that that panels on a garage would be considerably more difficult to install.

As far as presenting our project for consideration from the administration, Dr. Mathisen liked the idea of a catalog. He suggested inviting members of the sustainability faculty to our poster or powerpoint presentation, as well as any administrative members who might play a role in actually pursuing the project. Other advice offered included developing a solid argument for the benefits of solar panel canopies beyond economics and to have a well laid out executive summary.

We concluded the interview by thanking Dr. Mathisen for taking the time to meet with us and he encouraged us to reach out again and keep him updated on our progress.

Interview with WPI Associate Director of Sustainability Ms. Elizabeth Tomaszewski, 12 April 2019 @ 0900:

Questions:

1. We are looking to make a proposal or recommendation to someone in administration about the most feasible options for a solar canopy, is there an individual or a group of people we should look to speak to?
2. Is there a specific format we should present our findings? For example a catalog or more formal presentation?
3. Do you have any advice for our group as far as making a proposal?
4. How have similar past projects been successful in making proposals or recommendations and gaining support?
5. Is there anything else important you would like to add that we didn't ask or talk about?

We met for an informal interview with Ms. Tomaszewski to follow up with information we had presented to Dr. Mathisen. She also supported the idea of using a catalog to further present our information, and mentioned how it is something that could be easily kept on file. She mentioned that one of the major perks of having a canopy would be to help solve a current issue of not having enough charging stations for electric vehicle. They were unable to obtain budget to expand the current system last year, which was estimated to cost approximately $30,000. The location for the chargers was set to be in a Gateway lot.

She suggested we look into contacting UMass Amherst for more information on their system with solar. Ms. Tomaszewski also made reference to a previous proposal to the green revolving fund for a canopy system, saying how 3-6 structures were proposed to double as a car charging station. She mentioned many people in Facilities, and gave us a list of names we could look into contacting. She wasn't completely sure, but she knew one of the individuals she provided contact information for would be ultimately responsible for making the decision to implement the canopy. She gave us contact information for: Ron O'Brien (Director of Design and Construct), William Spratt (Director of Facilities Operations), William Grudzinski (Chief Engineer), Glenn Myers (Associate Director of Mechanical Services), and Alan Carlsen (Manager, Grounds & Properties).

Ms. Tomaszewski supported the idea of a power purchase agreement, especially considering how conservative WPI is with money. She mentioned how for most projects to be improved that there must be a payback period of 7 years or less. A tax manager would be a useful addition to ensure that WPI is going about the project in the most economically feasible manner.

We were informed of benefits besides the obvious economic benefits. She mentioned the educational aspect that would be associated with having a structure at WPI for students and faculty. Students can conduct research and a future project could create a display on site with the information and specifications of the system in place.

We concluded the informal interview with Ms. Tomaszewski by thanking her for her time and she encouraged us to keep her updated.