INTERIM 2015

SOLAR PV PROJECT

CALVIN COLLEGE

ENGINEERING W-80 A

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Executive Summary

Project Introduction

The goal of this project was to determine what it would take for Calvin College to construct, own, operate, and maintain a solar photovoltaic (PV) electricity generation system. There were four main task forces involved in achieving the goal: Building and Site Integration, Panel and Inverters, Finance, and Marketing.

Procedure

Determining a building on Calvin's campus that would be most ideal for a solar PV system was the first step in the process. The team focused its efforts on the buildings that make up the Spoelhof Fieldhouse Complex, namely: The Van Noord Arena, Venema Aquatic Center and the Huizenga Tennis and Track Center (T&T). Once the building was selected, the next step was to determine the energy needs of that building. With the energy needs of the building determined, a solar array to meet the needs could be designed. A full financial analysis was conducted on the different design options.

Results

The design team came up with three different proposals based upon the amount of money that would become available for such a project. The three designs outlined below are further described in Sections 7 – 9. The maximum lifetime of a panel can be estimated to be 40 years so the payoff of both the Net Zero and Max Area designs falls within the lifetime of the panels while the 500K is just longer than the life of the panels.

Table 1: Summary of Three Design Options

	500K	Net Zero	Max Area
System Size [kW]	153	671	799
Initial Cost [$]	$498,872	$1,928,758	$2,287,204
Payback Time [years]	41	34	34
Initial Cost [$/W]	3.26	2.87	2.86
Average Yearly Savings [$/yr]	$12,452	$54,820	$64,978
Yearly Spend Rate [%]	2.50	2.84	2.84

Conclusions

From a strictly financial standpoint, implementing any of these design options makes little sense because of the long payback periods. It would make more sense to put this amount of money into the endowment fund and use the interest to pay the electricity bills or reduce the college's debt. At this time the payoff times are quite long, but it is possible that panel and labor costs will significantly decrease over the next couple years so that the payback times decrease.

Despite the financial considerations, a solar array such as this does align with the values that Calvin College holds dear. Choosing one of these designs would help Calvin to significantly reduce the carbon emissions that it is responsible for by reducing its dependency on the grid, which is powered predominately by fossil fuels. This reduction in emissions ties in closely with Calvin's values of stewardship and sustainability, in the way that it uses the resources that God has given, to mitigate the environmental impact of the college.

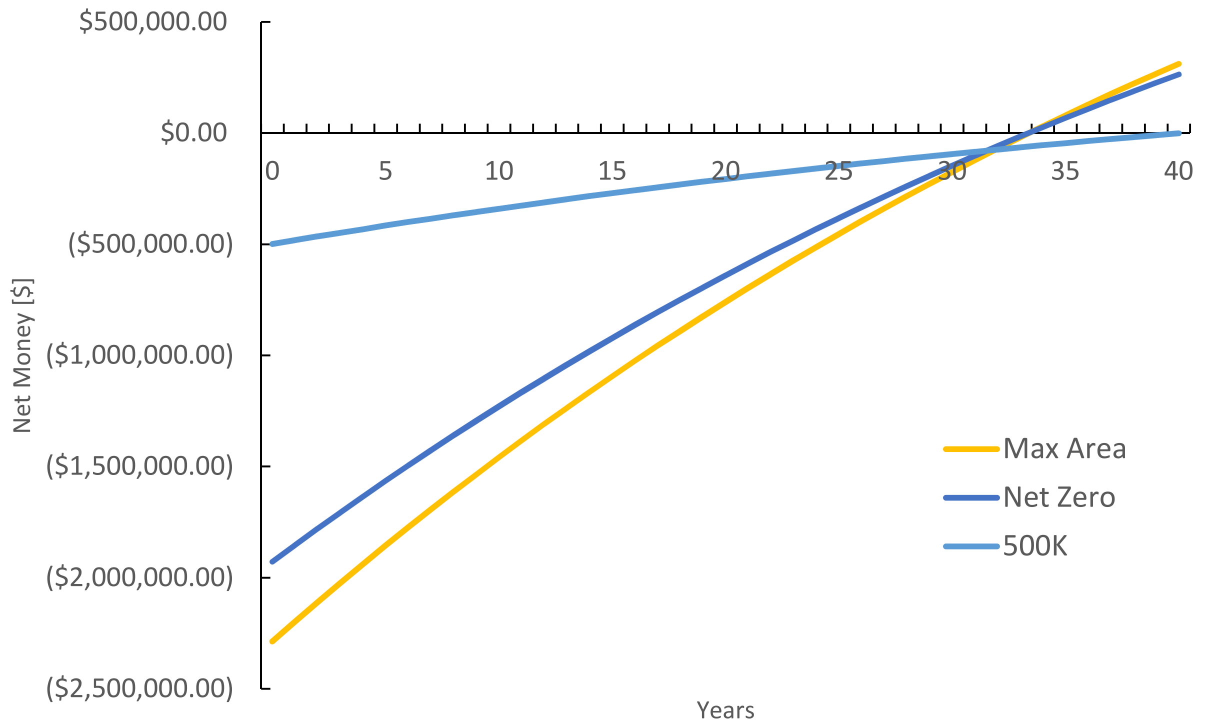

Figure 1: Solar Panel Array Payback

Finally, an upgrade to the campus, such as a solar array, needs to be looked at as an infrastructure investment more than a way to save money on electricity bills. A solar PV array should be important to the college because it will show prospective donors and students that stewardship is something that is truly valued. It might even be a way to draw in more students and provide more opportunities for current students to learn about alternative energy and stewardship at the same time.

For these reasons, the design team believes that Calvin College should pursue the Net Zero design as shown in Table 1. This design is marketable because it meets the need of an entire building, and at the same time reinforces the institution's commitment to stewardship and sustainability.

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1. Introduction

The goal of this project was to determine what it would take for Calvin College to construct, own, operate, and maintain a solar photovoltaic (PV) electricity generation system.

a) Task Forces

There were four main task forces involved in analyzing the feasibility of this project: Building and Site Integration, Panel and Inverters, Finance, and Marketing. The general responsibilities of each task force are listed below.

i. Building and Site Integration Task Force

This task force was responsible for selecting an appropriate site for installation of the solar PV generation system. They handled the solar array layout and racking system as well as the roof safety system necessary for PV panel installation.

ii. Panel and Inverter Task Force

This task force was responsible for selecting solar panels, inverters, and associated hardware to convert solar energy into conventional AC electricity. The group utilized Sunny Design software heavily to construct and optimize a series of panel layout scenarios and calculate the associated power production and costs. The panel and inverter task force also planned how the generated electricity would be integrated into the Calvin College power grid.

iii. Financial Task Force

This task force was responsible for providing a fiscal analysis template that automatically updated for any bill of materials. More responsibilities consisted of investigating power purchase agreements, net-metering, grants, loans, and rebate opportunities. The members of this team finished with a recommendation on the best solar case, if any, to pursue using payback analyses and comparisons to alternative energy projects.

iv. Marketing Task Force

This task force was responsible for creating a marketing framework for the generation options chosen by the other three task forces. This group determined the best marketing schemes to maximize the funding pool necessary for the solar project through market and demographic research.

2. How Solar Photovoltaic Power Works

a) Solar Panel Basics

There are three main types of solar panels including thin-film, polycrystalline, and monocrystalline. Thin-film solar panels are the cheapest variety, but suffer from low efficiency (typically between 7-13%) and durability. With efficiencies ranging from 13-16%, polycrystalline panels fall in the middle of the range of both efficiency and price. While they are cheaper than monocrystalline panels, they have lower space efficiency and possess lower heat tolerance. Monocrystalline panels are made from the highest grade silicon and provide the best efficiency available in solar panels. Ranging from 15-21%, monocrystalline panels have the highest space efficiency available. Monocrystalline panels also have the longest lifespan, but come at the highest price.

Solar Photovoltaic systems use cells to convert sunlight into electricity. Each cell consists of one or two layers of a semiconductor material such as silicon. As sunlight hits the cell, an electric field is created across the layers causing electricity to flow. Direct current (DC) electricity then flows to an inverter where it is converted to alternating current (AC). Figure 1Figure 2below shows a flow diagram of a PV system.

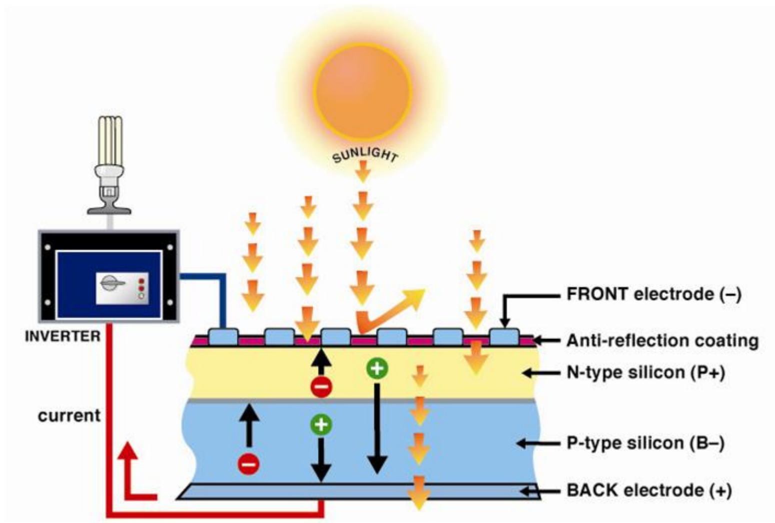


Figure 2: Photovoltaic System Function [1]

b) Solar Inverter Basics

Solar panels produce power in the form of DC electrical current. The majority of power consumption in residential and commercial buildings, as well as the power coming into the buildings from the grid, operate on AC current. This means the power produced from panel strings must be converted from DC (usually 600-1000V) to AC (typically 120V single phase or 480V three phase).This task is accomplished through the use of an inverter. These devices convert DC power to AC power by switching the DC current back and forth over a circuit known as an H-bridge as shown in Figure 3.

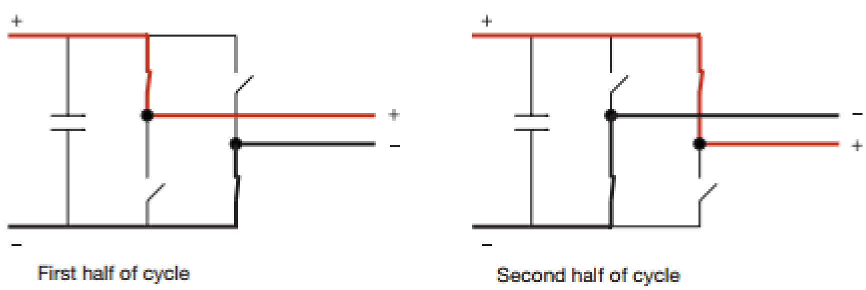


Figure 3: H-bridge Used to Convert DC Current to AC Current [1]

i. Maximum Power Tracking

The goal of a quality inverter is not only to convert the DC current, but to maximize the power output from the solar panel strings. Most inverters use maximum power point tracking (MPPT) to draw the maximum possible power from a panel string at any given point by varying the current draw depending on the temperature and voltage of the panels. Figure 4 shows an example of an I-V curve at which a set of solar strings may operate.

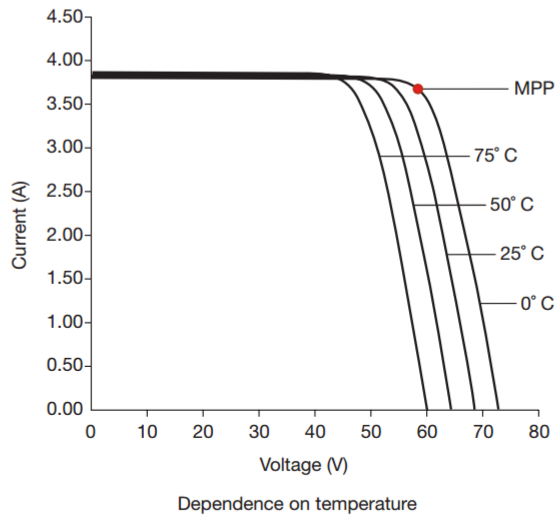


Figure 4: Maximum Power Point Tracking I-V Curve in a Typical Solar Inverter [1]

ii. Safety and Precautions

Solar inverters must have several features protecting the inverter circuitry and those working on or around them. One of the most important safety characteristics of grid-tied inverters (or those tied to the Calvin College main loop, in this case) is anti-islanding protection. This allows inverters to automatically shut down in the case of a grid shutdown in order to protect line workers from unexpected current generation. Other safety features include DC and AC side shut-off switches, allowing workers to perform any necessary maintenance, as well as lightning protection circuits on the DC and AC sides.

iii. Heat Generation

All inverters will generate a small amount of heat during normal operation. Inverter efficiencies range from 95-98%, meaning most of the electrical energy that enters the DC side of the converter will be passed through the inverter as AC electrical energy [2]. 2-5% of the energy will be converted to heat within the circuitry. The heat generation associated with any set of inverters is an important consideration as appropriate climate conditions lead to longer life and higher efficiency in all solar inverters.

c) Solar Power in Michigan

While it is a well-known fact that solar energy potential is less in Michigan than other states, Figure 5 below shows that solar PV is still a viable source of renewable energy. Provided by the National Renewable Energy Laboratory (NREL), the figure shows solar radiation levels across the United States for the month of July in kWh/m^2/day. While Michigan's solar resource is near the low end, PV systems are still feasible.

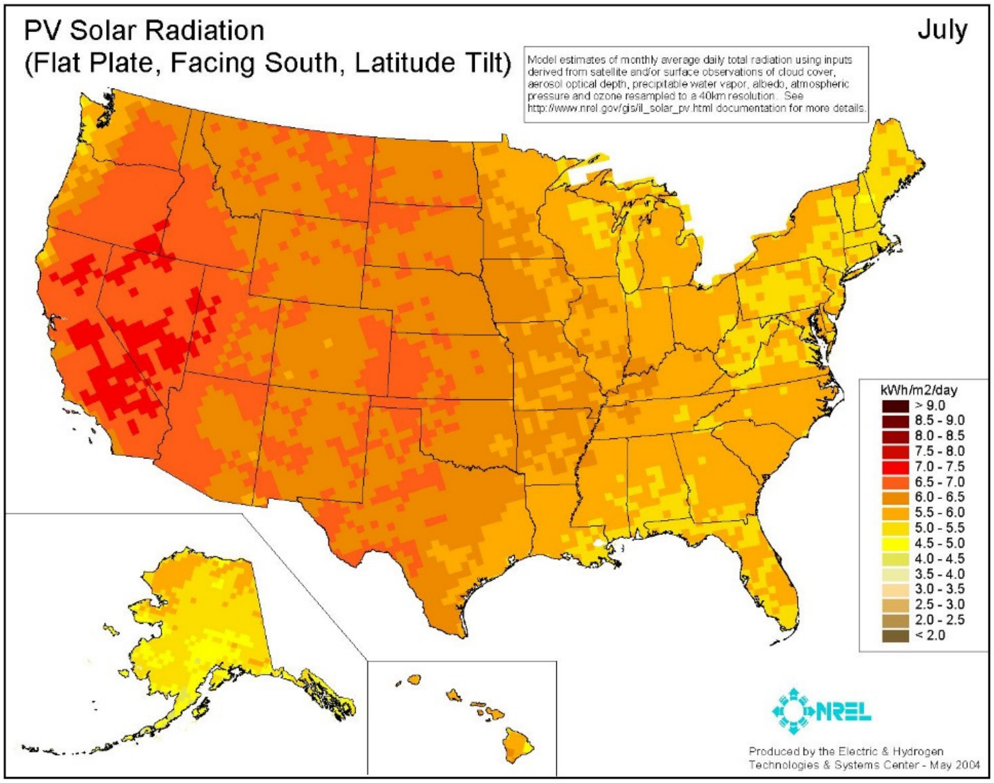


Figure 5: PV Solar Radiation [3]

3. Site Selection

Multiple locations on Calvin's campus were studied to determine which building could most realistically handle a solar array on its roof. The design team focused its efforts on the buildings that make up the Spoelhof Fieldhouse Complex, namely: The Van Noord Arena, Venema Aquatic Center and the Huizenga Tennis and Track Center. These buildings were chosen because of the large open roof area compared to the other buildings on campus. The area of any of these roofs would allow an array of substantial size to be installed in order to offset a sizeable fraction of the facility's annual energy use. The three options are shown below in Figure 6 with top of the image facing north**.** The following sections will outline the three options and benefits of each.

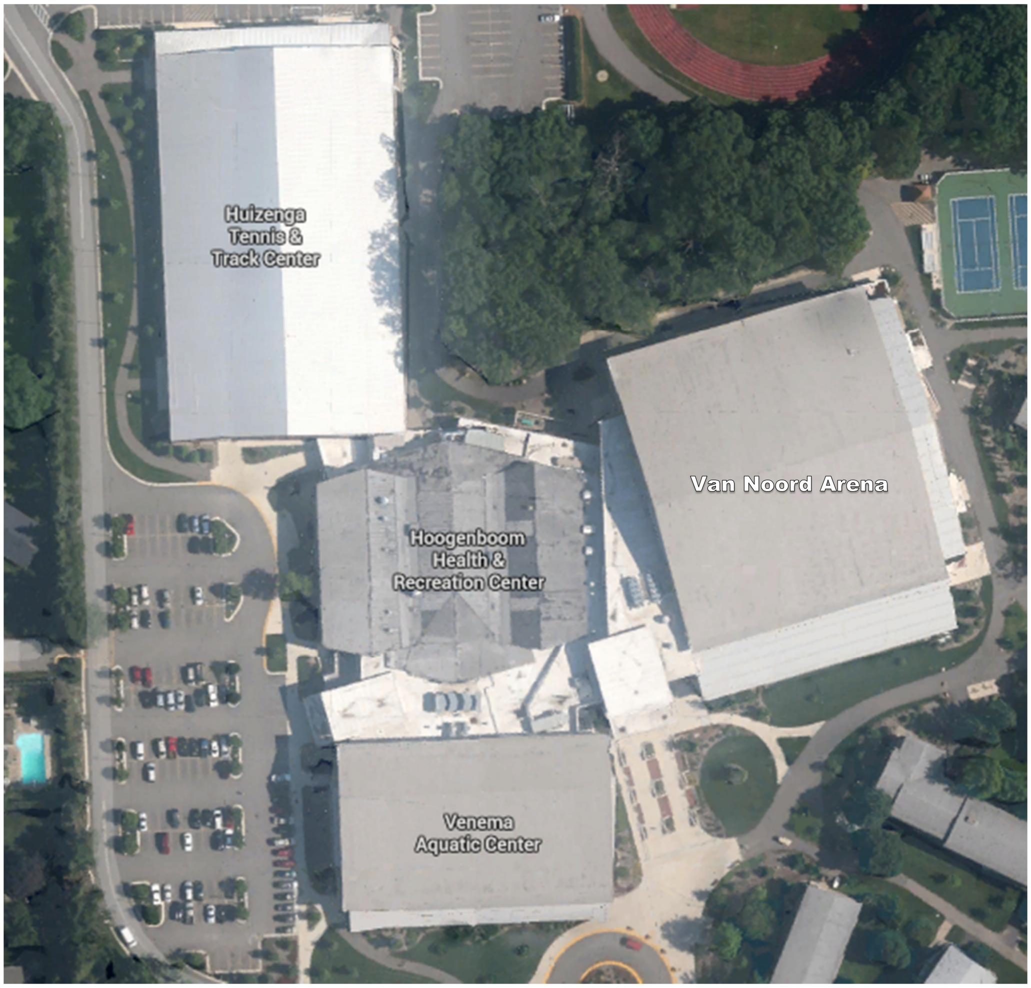


Figure 6: Calvin College Recreational Facilities [4]

The Venema Aquatic Center has a roof which has a north/south orientation and a slope of 3"/12" (14°) which is ideal for solar production capability. However the roof is very difficult to access because of its exceptional height. This would make installation and maintenance difficult and rather dangerous. The surface is a pebble roof which is a combination of membrane roofing with tiny rocks on top. The lifespan of this type of surface is approximately thirty years and would most likely need to be replaced during the lifetime of the solar array which would mean a costly disassembly and reinstallation of panels once the roof is replaced. Lastly, this building has a very high energy usage which would be very difficult to meet with an array based solely on this roof. This is due to the lighting, air conditioning, and pool equipment such as pumps that are used almost constantly. This makes putting an array on this building less marketable because the opportunity to generate all the building's needs is not there.

The Van Noord Arena has a roof which is oriented to the northwest and southeast and has nothing around it which could shade the roof. The available area on the roof is also quite expansive. This means that the production opportunity for this roof is quite high. However the roof on the arena is also quite high making it difficult to access. This would make installation and maintenance difficult and rather dangerous. The surface is a pebble roof similar to the aquatic center so it is undesirable for the same reasons. Lastly this building has a very high energy usage which would be very difficult to meet with an array based solely on this roof. The energy usage is high because of the lighting, air conditioning, and pool equipment such as pumps that are used almost constantly. This makes putting an array on this building, less marketable because the opportunity to generate all the building's needs is not reality.

The Huizenga Tennis and Track Center is the northernmost building of the complex. The roof is oriented in the east/west direction. This is not ideal for production capability because the intensity is about 15% less as compared to a north/south orientation. Although the orientation is not ideal, the Tennis and Track Center (T&T) has the largest roof of the three options at 63,744 square feet. It is covered in standing seam metal roofing with two foot gaps between the seams. This type of roof has a long life span (roughly 100 years) which would eliminate the need to replace the roof within the lifetime of a solar array. The roof has a slight slope of 2.5"/12" (11.8°) and is the lowest of the three options. This is a benefit because it makes installation of the panels much safer, as well as the maintenance of them. Finally, the energy usage in the T&T is low compared to the other two options because there is no air conditioning. The main draw of the building is the lights, which were replaced in 2014 with LEDs. Because of the low draw of the building, it would be feasible to meet the electricity needs of the T&T with an array based solely on the roof.

The team decided on pursuing a design based on the roof of the T&T for a few different reasons. First of all, the roof is large enough to handle an array which could provide all of the T&T's annual needs, without being highly visible. Making the T&T Net Zero would be a very marketable option for the college. Secondly the type of roof played a big role in this decision. The metal roofing makes mounting a solar array quite easy, and would require no penetrations into the roof to mount the panels themselves. The available racking systems for metal roofs are also more affordable than the systems for a membrane roof. Finally, the roof on the T&T is the most accessible and safest roof of the three options proposed because of its low height and moderate slope.

4. Tennis and Track Center Energy Needs

The Huizenga Tennis and Track Center has a relatively low energy need for a building of its size. This low energy need is caused by several factors. First, the building has no air conditioning. During the summer months when air conditioning is necessary, most people choose to run on the outdoor track or the Calvin Loop rather than indoors at the T&T. In addition, the old metal halide lights in the T&T were replaced with LED fixtures in the spring of 2014. This project was implemented by the Calvin Energy Recovery Fund (CERF). The new LED lights are significantly more energy efficient than the metal halides, meaning that a solar array does not need to generate as much electricity to meet the energy demand of the T&T lighting.

Heating in the Tennis and Track Center is provided by two large air handler units in the utility room. Each unit is powered by a 75 horsepower motor. There are several other energy need sources in the T&T, including an additional small pump for the bathrooms and lighting in storage rooms.

First, the power load of the Tennis and Track Center was estimated by observing the current and voltage readings from the main circuit breaker in the Spoelhof Fieldhouse Complex. The current going to the T&T was 112 A while one of the two motors was running at 50% load. The motor was then turned off and the current was again observed. Using this difference, the current for a theoretical maximum power case was determined. In addition, the hours of use were estimated to be 16 hours (6 AM to 10 PM). The results of the first estimation method are summarized in Table 2, below.

Table 2: First Method of Determining Electricity Needs of Tennis and Track Center

Current [A]	148
Voltage [V]	480
Power [kW]	71.04
Daily Use [hr/day]	16
Yearly Energy Need [kWh]	415000

In order to analyze the T&T energy need from a bottom-up approach, the power draw of the T&T was estimated. For a maximum case, the motors were assumed to operate simultaneously at 60% load. This estimation covers the auxiliary pumps and lights that were not directly accounted for. Next, the yearly energy use of the LED lights was provided by CERF. The results of the second estimation method are summarized in Table 3, below.

Table 3: Second Method of Determining Electricity Needs of Tennis and Track Center

Motor Power [hp]	75
Motor Power [kW]	55.9
Number of Motors	2
Motor Operating Load [%]	60
Total Motor Power Draw [kW]	67.1
Daily Use [hr/day]	16
Yearly Motor Energy Need [kWh]	392000
Yearly Lighting Energy Need [kWh]	35000
Total Yearly Energy Need [kWh]	427000

427000 kWh per year was selected as the annual energy need of the Tennis and Track Center. This value is conservative, as motor use and LED lighting use was determined using a maximum amount of hours and performance. 427000 kWh served as the baseline for comparison of all solar panel array production results. This allowed the percent of T&T energy need being produced by the solar panel array to be calculated.

5. Panel and Inverter Selection

a) Panel Selection

The team began their initial research into solar panels using the Monocrystalline PV Ratings provided by the Principal Solar Institute on their website [5]. After noticing that 19 of the top 20 rated panels were manufactured by SunPower, the team began to research this manufacturer extensively.

To help analyze the solar panels on the basis of cost, power, and area, a tool was developed to graph panels using axis of (Cost/Watt) and (Area/Watt). The closer to the origin any panel was, the better it was. Many panels were graphed and the analysis tool showed that SunPower was the best panel manufacturer with its X21 345W and E20 327W being the most cost efficient models. However when analysis was done on payback periods for these panels it was noticed that the LG 305N1C-B3 with only 305W had a quicker payback period. For this reason the LG 305N1C-B3 panel was chosen as the optimal panel for the Calvin College PV Array (Figure 8).

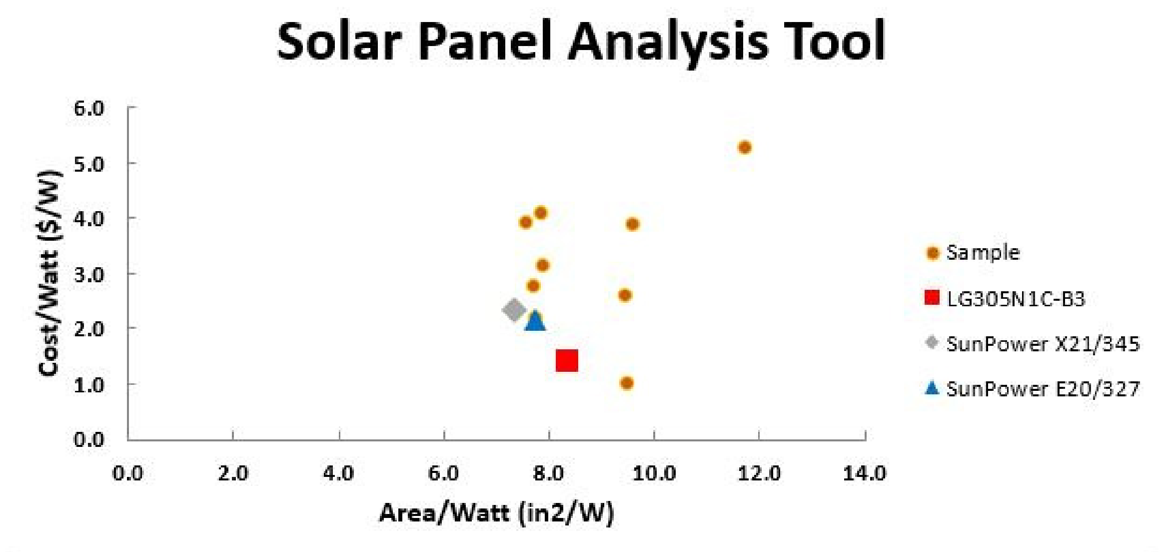


Figure 7: Panel Analysis Tool

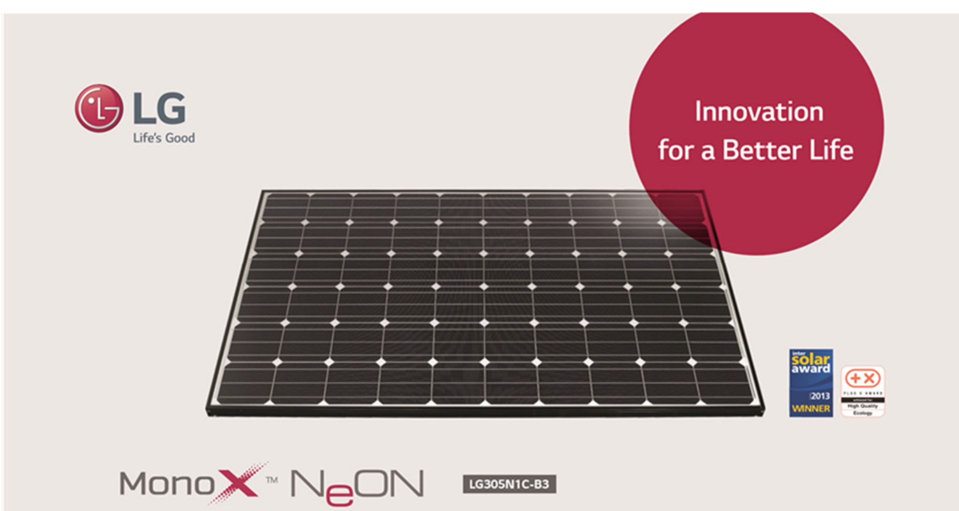


Figure 8: LG Mono X NeON Module [6]

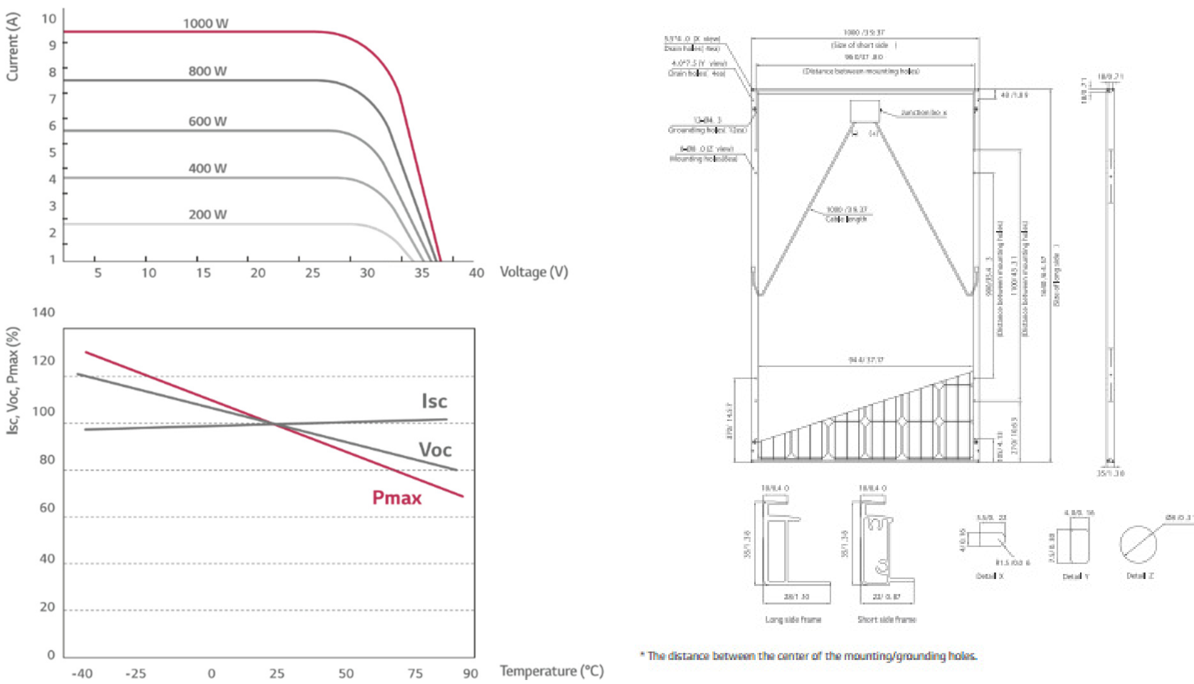


Figure 9: Electrical (left) and Physical (right) Panel Characteristics [6]

The electrical and physical characteristics of the LG panel can be found in Figure 9, above, and Table 4, below.

Table 4: Selected Panel Specifications [6]

Power [W]	305
Module Efficiency [%]	18.6
Annual Degradation [%]	0.7
Dimensions [in]	64.57 x 39.37 x 1.38
Weight [lb]	36.96

b) Inverter Selection Process

Inverters were chosen based on quality and price. A pool of high-grade inverters was created based on manufacturers' data-sheets and prices from civicsolar.com, a solar wholesale website (Table 5). The inverters with the best $/power capacity value were chosen for the project. SMA MLX 60 inverters and ABB Trio inverters showed the best price points at $186-$189/kW.

Table 5: Inverter Cost and Feature Comparison [7]

Price	Model	Power (kW)	Price/ Power ($/kW)	Input (VDC)	Output (VAC)	Efficiency	MPPT
$ 12,666.67	Kaco blueplanet 50 TL3 M3	50	$ 53.33	1000	480	97.5 (weighted)	480-850
$ 5,160.79	ABB TRIO-27.6-TL-OUTD-S-US-480	27.6	$ 86.99	1000	480	98.2 (max) 97.5 (weighted)	450-800
$ 4,542.46	ABB TRIO-20.0-TL-OUTD-S-US-480	22	$ 206.48	1000	480	98.2 (max) 97.5 (weighted)	520-800
$ 3,649.30	Fronius Symo Lite 15.0-3-M	15	$ 243.29	1000	480	98.1 (max), 97.0 (weighted)	350-800
$ 3,322.03	Fronius Symo Lite 12.5-3-M	12.5	$ 265.76	1000	480	98.1 (max), 97.0 (weighted)	350-800
$ 11,320.31	SMA MLX 60 w/ DC Switch	60	$ 188.67	1000	480	98.8 (max) 98.5 (weighted)	685-800
$ 6,950.72	SMA STP24000TL-US-10	24	$ 289.61	1000	480	98.5 (max), 98.0 (weighted)	450-800
$ 5,896.61	SMA STP20000TL-US-10	20	$ 294.83	1000	480	98.5 (max), 97.5 (CEC)	380-800
$ 5,260.20	SMA STP15000TL-US-10	15	$ 350.68	1000	480	98.2 (max), 97.5 (cec)	300-800
$ 4,852.08	SMA STP12000TL-US-10	12	$ 404.34	1000	480	98.5 (max), 97.5 (CEC)	300-800
$ 130,495.00	SMA SC 500CP-10-US	500	$ 260.99	1000	270	98.5	430-820
$ 130,247.00	SMA SC-500-US-10	500	$ 260.49	1000	480	98.5	430-820
$ 205,065.00	SMA 800CP-US-10	800	$ 256.33	1000	360	98.5	430-820

c) Primary Inverter

SMA MLX-60 inverters were chosen as the primary inverter for the project given their high power capacity at 60 kW (compared to the ABB capacity of 27.6 kW). The MLX 60 measures 29in x 22in x 12 and weighs 165 lb [8]. These inverters feature single MPPT's (maximum power point trackers) operating over a range of 685-800VDC. These inverters are built with shutoff switches and arc fault circuit interrupters (AFCI), but will require lightning protection circuitry on the AC and DC sides

Figure 10: SMA MLX 60 Inverter [8]

d) Secondary Inverter

To more efficiently utilize the full capacity of the solar arrays on the T&T roof, SMA Sunny Tripower (STP) series 12-24 kW inverters were chosen to fill the remaining power capacity (remaining power less than 60 kW). These inverters have the same features and requirements of the MLX-60, except for two MPPT's instead of one [2]. This simply means each inverter will take two string inputs instead of one.

Figure 11: SMA STP Series Inverter [2]

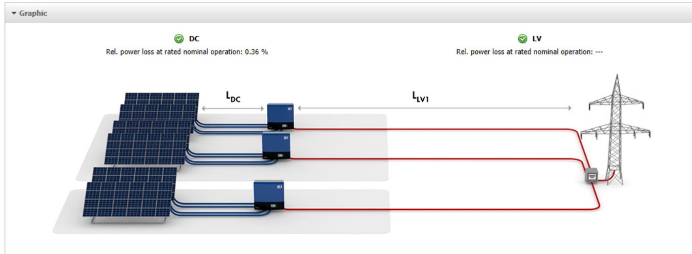
e) Combiner Boxes

The combiner boxes chosen for the system were the SolarBOS String Combiners family which have four models [9]: one for combining 4-12 strings, one for 14-18, one for 20-24, and another for 26-36 [9]. All of these boxes are made from stainless steel and were quoted from SolarBOS at $325.14. These boxes act to not only combine the strings of panels together before they go to the inverters, but also to act as surge protection using fuses and to multiply the current.

Figure 12: SolarBOS String Combiner [9]

Sunny Design is a solar PV system design program created by SMA Solar Technology. It allows the user to create solar PV systems by inputting location data, roof slope and orientation, and solar panel type and amount. Then, the program automatically (or manually) selects the number, type, and size of inverters necessary to handle the power of such a system. The program provides extensive analysis on the electrical results of the selection (such as inverter efficiency). It also estimates the yearly energy production, peak power, and other important results. Sunny Design is an essential tool for designing and analyzing solar PV systems.

Each setup was analyzed using Sunny Design. For each system, a West Roof and an East Roof array was created by orienting the roof in the proper direction, setting the roof slope to 11.7deg, and inputting the correct number of panels. The inverter design was automatically generated and then manually adjusted if simplifications could be made. The number of inverters was used to select the number and type of combiner boxes needed to combine the strings of panels into a single wire input for the inverter.



DC cables | Lines LV1 | Lines LV2 | Line LV3

		Cable material	Single length	Cross section	Current	Voltage	Voltage drop	Rel. power loss
T&T								0.36 %
Max Case								0.36 %
5 x MLX 60 (UL)	A	Copper	10.00 m	1,5 mm²	96.18 A	636.5 V	2 V	0.32 %
5 x MLX 60 (UL)	A	Copper	10.00 m	1,5 mm²	98.16 A	623.7 V	2 V	0.33 %
2 x STP 20000TL-US-10	A	Copper	10.00 m	1,5 mm²	30.64 A	394 V	2.3 V	0.59 %
	B	Copper	10.00 m	1,5 mm²	30.64 A	394 V	2.3 V	0.59 %
2 x STP 20000TL-US-10	A	Copper	10.00 m	1,5 mm²	30.79 A	386.1 V	2.4 V	0.61 %
	B	Copper	10.00 m	1,5 mm²	30.79 A	386.1 V	2.4 V	0.61 %

Figure 13: Sunny Design Project Summary Window

Sunny Design predicts the amount of energy generated by the solar PV system using the number of panels, orientation and slope of the roof, and geographic location data. This is a generally optimistic prediction, as it does not account for possible tree shade, snow cover, downtime for maintenance, and other factors that could lower production.

Therefore, historical solar PV production data from the Bunker Interpretive Center at Calvin College was also used to estimate the possible production from a T&T solar array. The Bunker Interpretive Center has a thin-film solar panel array on its east- and west-facing roofs that was constructed in 2004. The panels are approximately 6% efficient and sit in between the raised ridges of the metal roofing. There is tree cover on both sides of the roof, which further limits its energy production. The energy production of a T&T solar array was predicted by scaling the Bunker Interpretive Center data by both the increased efficiency of monocrystalline panels and the larger roof surface area. This was considered to be a conservative estimate because the T&T has less tree cover (minimal cover on the lower portions of the east-facing roof) and the panels do not sit in trays like the panels at the Bunker Interpretive Center.

The conservative estimates from the Bunker Interpretive Center historical data and the optimistic estimates from Sunny Design were significantly different. The Sunny Design prediction was often double the Bunker Interpretive Center prediction for each system design. In order to establish a realistic estimate for use in this design and analysis process, an arithmetic average was taken between the two predictions. This allowed for reasonable financial payback analysis.

6. 500K Option

Staying within the budget of $500,000 was the most important thing in this model. The goal of this model was to get as much energy production from as many panels as the limited budget allowed. The panels are oriented in a horizontal fashion for ease of mounting and installation. The panels are grouped into blocks that span the entire length of the roof.

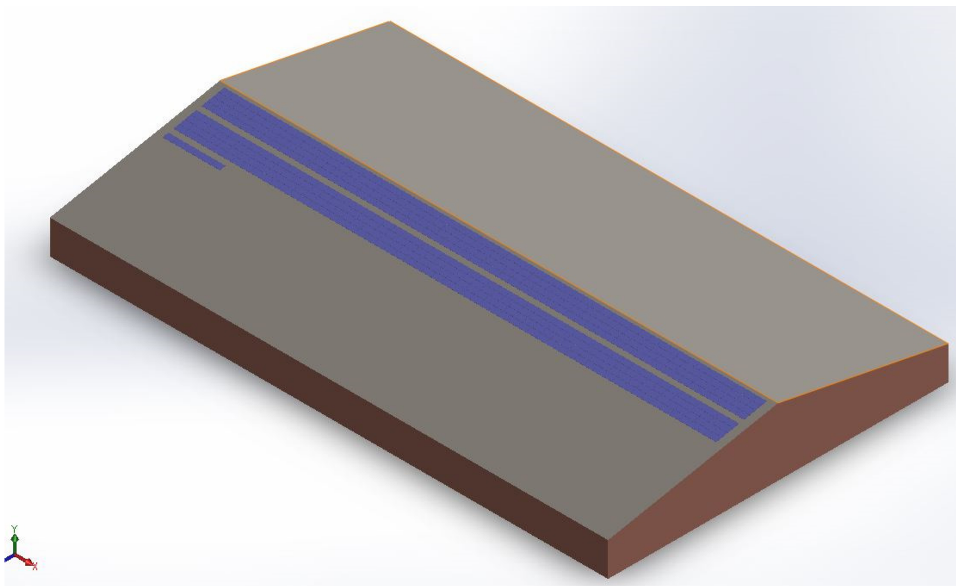


Figure 14: 500K Panel Layout

Table 6: 500K System Overview

Panels	500
Inverters	2 x SMA MLX 60 1 x SMA STP 12000TL
Peak Power	141 kW
Yearly Production	170.38 MWh
% of T&T Energy Need	33%
Roof Load	20,000 lb

Two MLX 60 inverters and one STP 12 inverter will be used for the $500,000 budget case, for a maximum power generation capacity of 141 kW. Table 7 shows the inverter, combiner box, and panel string organization for this case. Table 7 also shows the maximum possible heat generation from the inverter set in terms equivalent number of 1500 W space heaters. The information in Table 7 is shown in graphical form in Figure 15. Note that each solar diode symbol in the diagram below represents a single string of solar panels. The number of panels in each string is shown in the box next to the string grouping. The number below each combiner box represents the number of string inputs for that box.

Table 7: Inverter, Combiner Box, and Panel String Organization

Inverter	Number	Panels	Strings/Box	Panels/ String	Combiner Boxes	String Power (kW)	Power to Inverter (kW)	Max Heat Output (kW)	Electric Heater Equivalent
MLX 60	2	462	11	21	2	6.405	70.455	2.40	2
STP 24	-	-	-	-	-	-	-		
STP 20	-	-	-	-	-	-	-		
STP 15	-	-	-	-	-	-	-		
STP 12	1	60	2	19	1	5.795	11.59		

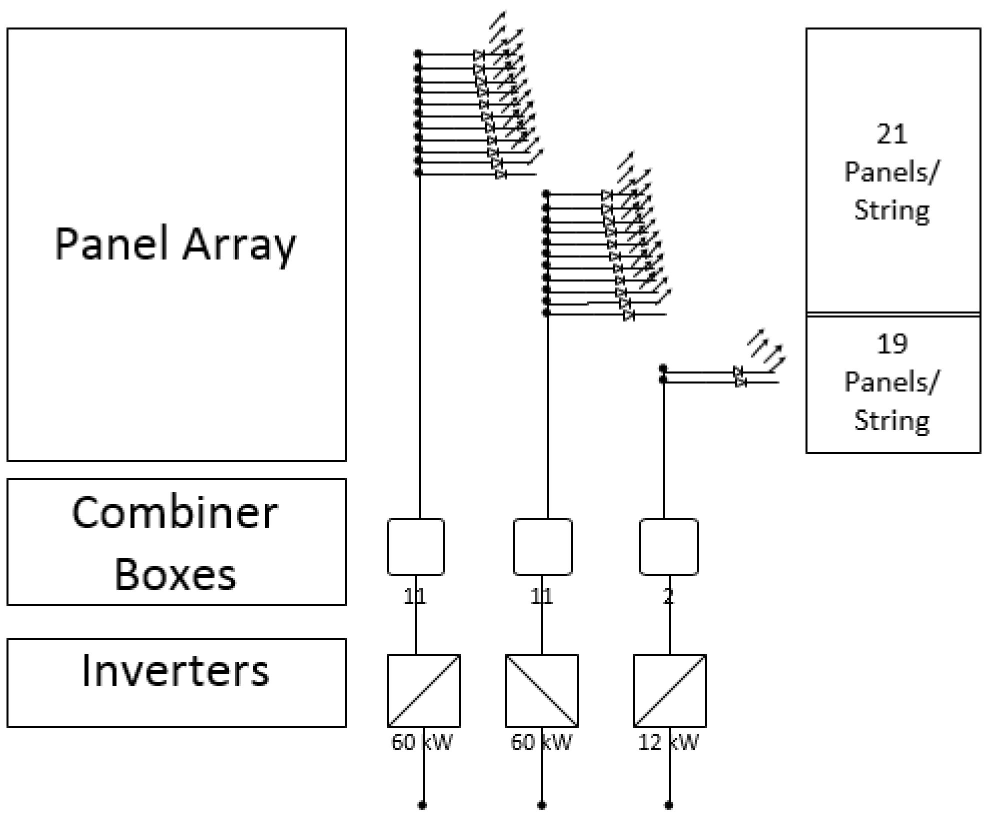


Figure 15: Inverter, Combiner Box, and Panel String Diagram

Table 8 shows projected maximum current from each set of inverters as well as the necessary AWG wire gauge for each cable run. Note that all inverters have been combined into a single cable run given the relatively low power of this case. Figure 16 shows a diagram of the inverter combinations and cable runs between the inverters and the complex power grid.

Table 8: Inverter Power Distribution Plan

Inverter	Number	Total Power (kW)	Total Current (A)	Combined Current (A)	Number of Cable Runs	Current/Cable Run (A)	Current/Cable (A)	Wire Gauge
MLX 60	2	120	250	275	1	275	91.7	2
STP 24	-	-	-					
STP 20	-	-	-					
STP 15	-	-	-					
STP 12	1	12	25					

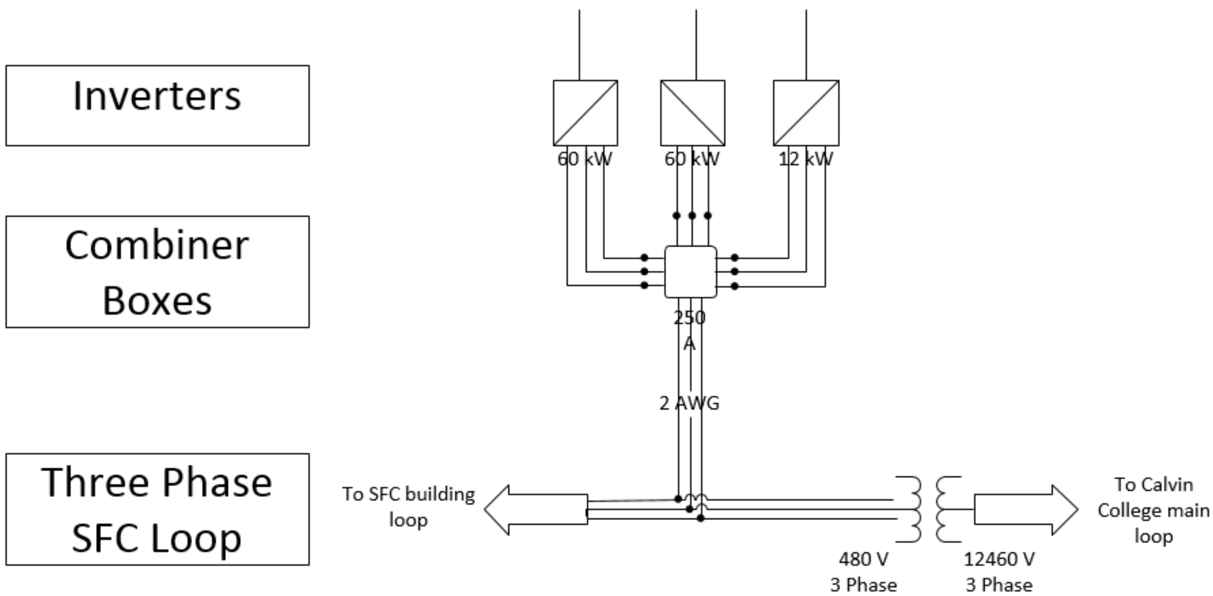


Figure 16: Power Grid Connection Diagram

A short summary of the costs associated with this option can be found in Table 9.

Table 9: Financial Summary of 500K System

Panels and Inverters	$ 243,992
Balance of System	$ 331,520
Labor	$ 122,000
Contingency (10%)	$ 45,352
Total	$ 498,872

7. Net Zero Option

Meeting 100% of the energy needs for the T&T was the most important consideration for the Net Zero model. The goal of this model was only to use as many solar panel as needed to make the T&T Net Zero from an electricity standpoint. It is important to note that a very conservative energy production prediction was used. Producing 100% of the T&T's energy needs was based off of the Bunker Interpretive Center historical data prediction, not off the Sunny Design prediction or an average between the two. This should ensure that the system presented here generates 100% of the T&T's energy needs even based off a very conservative estimate. The panels are oriented in a horizontal fashion for ease of mounting and installation. The panels are grouped into blocks that span the entire length of the roof. The blocks are 57 panels long and 4 panels tall. Each full block contains 228 panels. In total there are nine full blocks and one partial block of 57 by 2 panels and an additional partial row of 31 panels. In total there are 2,200 panels on the roof. This layout will produce a peak power of 0.671 MW and have a yearly production of 821 MWh. The weight per panel is 40 lb and the weight of the total design, including the racking system, is estimated to be 91,300 lb. This estimate will need to be verified and the structural integrity of the T&T check by a structural engineer. This design can be seen in Figure 17 below.

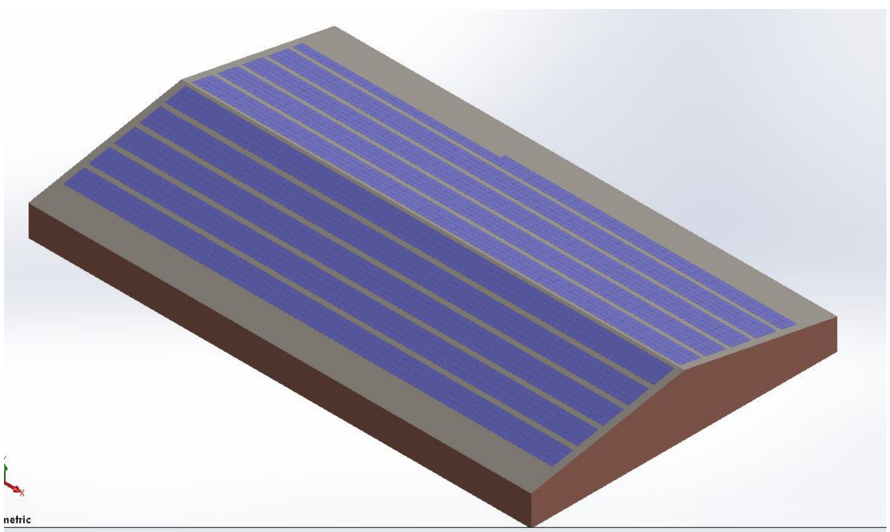


Figure 17: Net Zero Panel Layout

Table 10: Net Zero System Overview

Panels	2200
Inverters	10 x SMA MLX 60
Peak Power	671.0 kW
Yearly Production	812.48 MWh
% of T&T Energy Need	147%
Roof Load	91,300 lb

Ten MLX 60 inverters will be used for the Net Zero case, for a maximum power generation capacity of 600 kW. Table 11 shows the inverter, combiner box, and panel string organization for this case.

Table 11 also shows the maximum possible heat generation from the inverter set in terms equivalent number of 1500 W space heaters. The information in Table 11 is shown in graphical form in Figure 18. Note that each solar diode symbol in the diagram below represents a single string of solar panels. The number of panels in each string is shown in the box next to the string grouping. The number below each combiner box represents the number of string inputs for that box.

Table 11: Inverter, Combiner Box, and Panel String Organization

Inverter	Number	Panels	Strings/ Box	Panels/ String	Combiner Boxes	String Power (kW)	Power to Inverter (kW)	Max Heat Output (kW)	Electric Heater Equivalent
MLX 60	10	2200	10	22	10	6.71	67.1	10.07	6
STP 24	-	-	-	-	-	-	-		
STP 20	-	-	-	-	-	-	-		
STP 15	-	-	-	-	-	-	-		
STP 12	-	-	-	-	-	-	-		

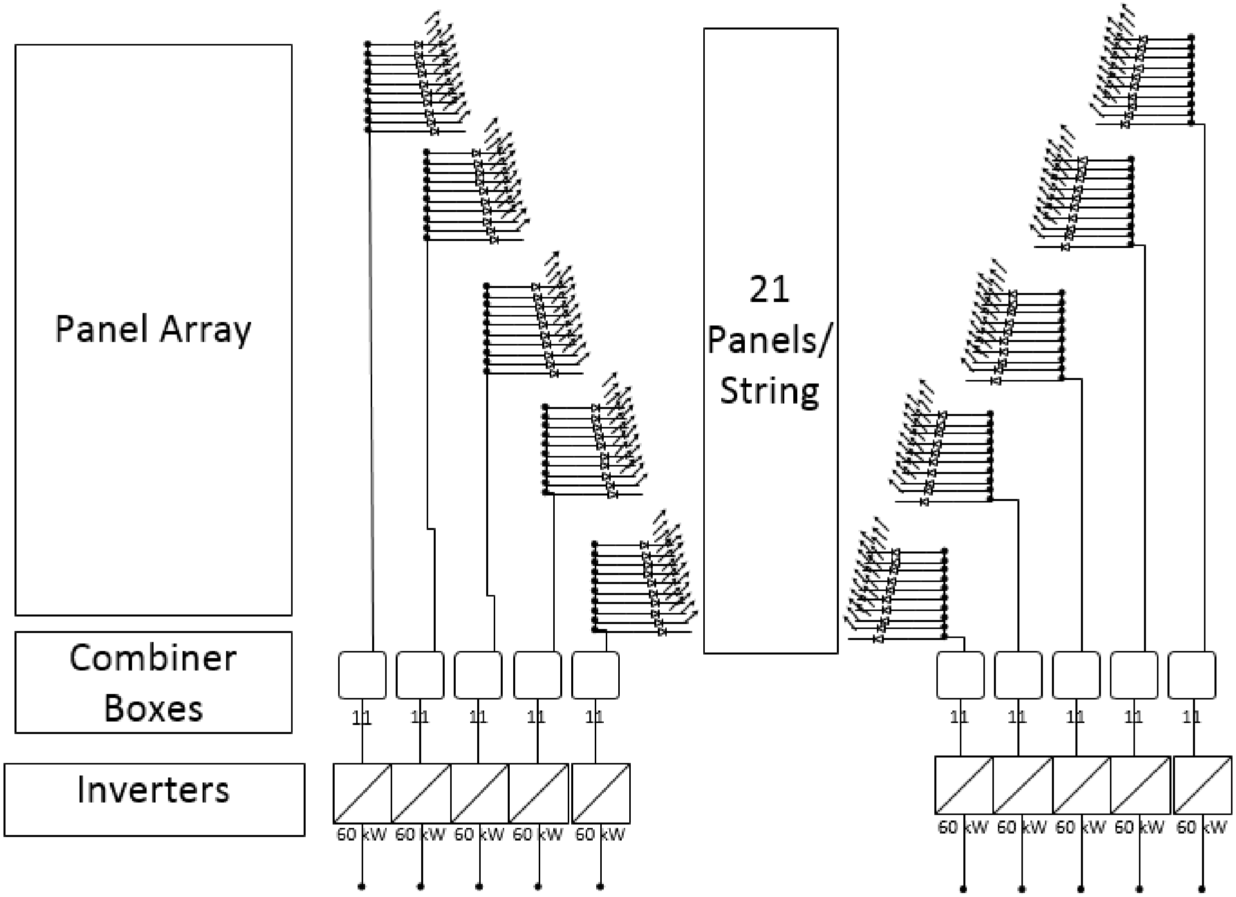


Figure 18: Inverter, Combiner Box, and Panel String Diagram

Table 12 shows projected maximum current from each set of inverters as well as the necessary AWG wire gauge for each cable run. Figure 19 shows a diagram of the inverter combinations and cable runs between the inverters and the complex power grid.

Table 12: Inverter Power Distribution Plan

Inverter	Number	Total Power (kW)	Total Current (A)	Number of Cable Runs	Current/Cable Run (A)	Current/Cable (A)	Wire Gauge
MLX 60	10	600	1250	2	625	208.3333	OOO
STP 24	-	-	-	-	-	-	-
STP 20	-	-	-	-	-	-	-
STP 15	-	-	-	-	-	-	-
STP 12	-	-	-	-	-	-	-

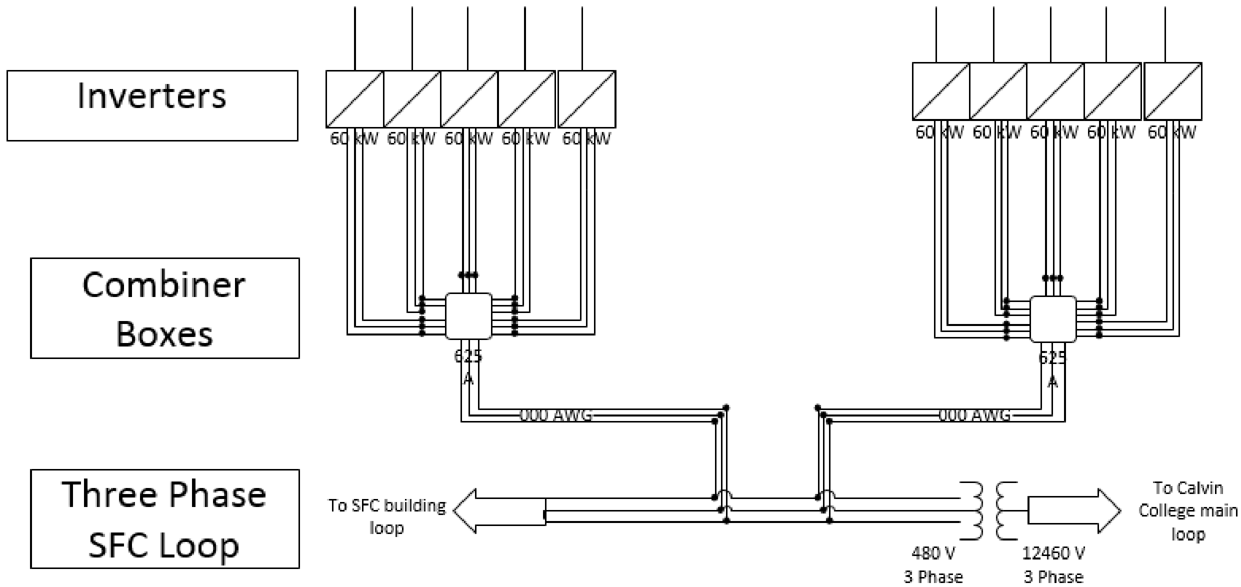


Figure 19: Power Grid Connection Diagram

A short summary of the costs associated with this option can be found in Table 13.

Table 13: Financial summary of Net Zero Option

Panels and Inverters	$ 1,065,803
Balance of System	$ 1,216,616
Labor	$ 536,800
Contingency (10%)	$ 175,341
Total	$ 1,928,758

8. Max Area Option

The layout of the solar panels was the most important factor in the max production model. The goal of this model was to use as much space on the roof as possible to get the most energy production possible. The panels are oriented in a horizontal fashion for ease of mounting and installation. The panels are grouped into blocks that span the entire length of the roof. The blocks are 57 panels long and 4 panels tall. Each full block contains 228 panels. In total there are ten full blocks and two smaller blocks of 57 by 3 panels. In total there are 2,622 panels on the roof. This layout will produce a peak power of 0.799 MW and have a yearly production of 963 MWh. The weight per panel is 40 lb and the weight of the total design, including the racking system, is estimated to be 108,880 lb. This estimate will need to be verified and the structural integrity of the T&T check by a structural engineer. This design can be seen in Figure 20 below.

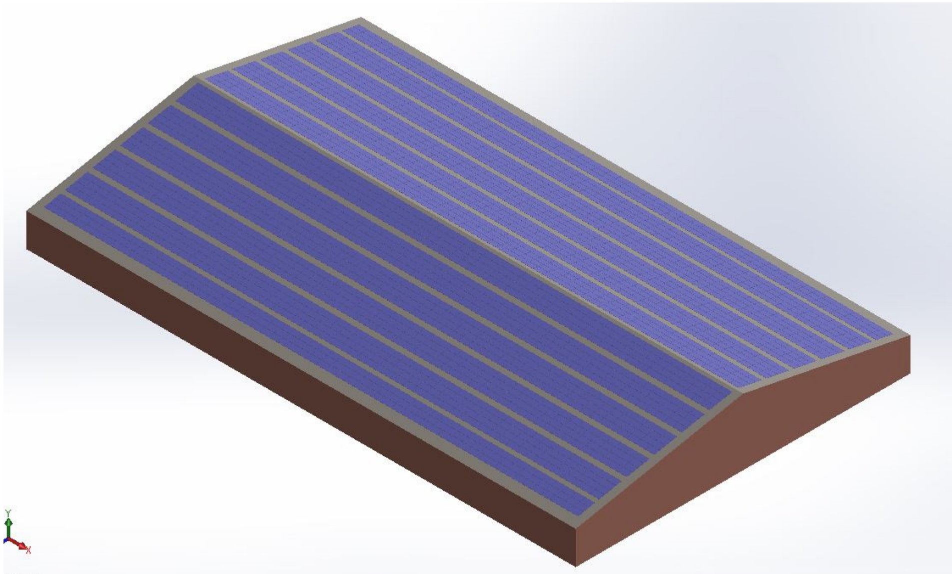


Figure 20: Max Area Panel Layout

Table 14: Max Area System Overview

Panels	**2622**
Inverters	10 x SMA MLX 60 4 x STP 20000TL
Peak Power	799.71 kW
Yearly Production	963.88 MWh
% of T&T Need	174%

Ten MLX 60 inverters and four STP 20 kW inverters will be used for the maximum coverage case, for a maximum power generation capacity of 800 kW. Table 15 shows the inverter, combiner box, and panel string organization for this case. Table 15 also shows the maximum possible heat generation from the inverter set in terms equivalent number of 1500 W space heaters. The information in Table 15 is shown in graphical form in Figure 21. Note that each solar diode symbol in the diagram below represents a single string of solar panels. The number of panels in each string is shown in the box next to the string grouping. The number below each combiner box represents the number of string inputs for that box.

Table 15: Inverter, Combiner Box, and Panel String Organization

Inverter	Number	Panels	Strings/Box	Panels/String	Combiner Boxes	String Power (kW)	Power to Inverter (kW)	Max Heat Output (kW)	Electric Heater Equivalent
MLX 60	10	2520	10	21	10	6.405	64.05	11.99	8
STP 24	-	-	-	-	-	-	-		
STP 20	4	90	6	13	4	3.965	23.79		
STP 15	-	-	-	-	-	-	-		
STP 12	-	-	-	-	-	-	-		

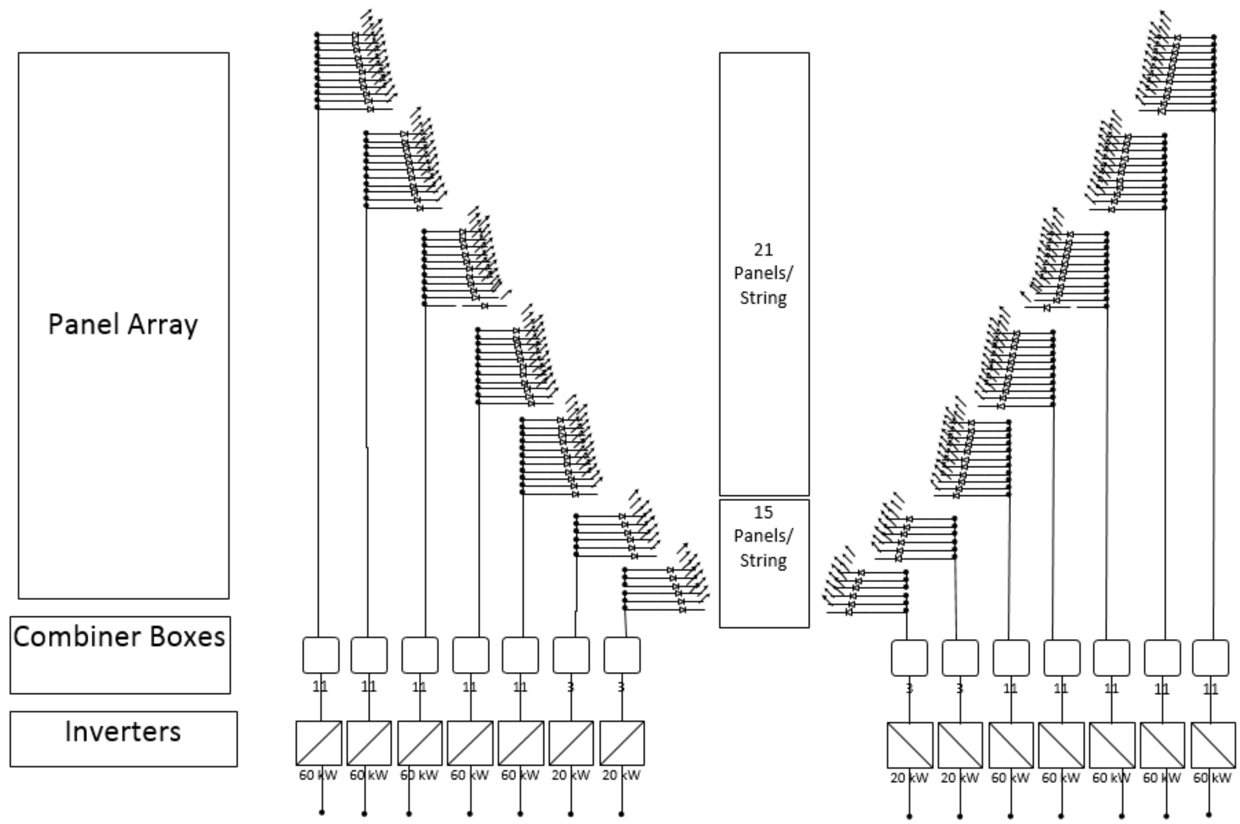


Figure 21: Inverter, Combiner Box, and Panel String Diagram

Table 16 shows projected maximum current from each set of inverters as well as the necessary AWG wire gauge for each cable run. Figure 22 shows a diagram of the inverter combinations and cable runs between the inverters and the complex power grid.

Table 16: Inverter Power Distribution Plan

Inverter	Number	Total Power (kW)	Total Current (A)	Number of Cable Runs	Current/Cable Run (A)	Current/Cable (A)	Wire Gauge
MLX 60	10	600	1250	2	625	208.3	OOO
STP 24	-	-	-	-	-	-	-
STP 20	4	80	167	1	167	55.6	4
STP 15	-	-	-	-	-	-	-
STP 12	-	-	-	-	-	-	-

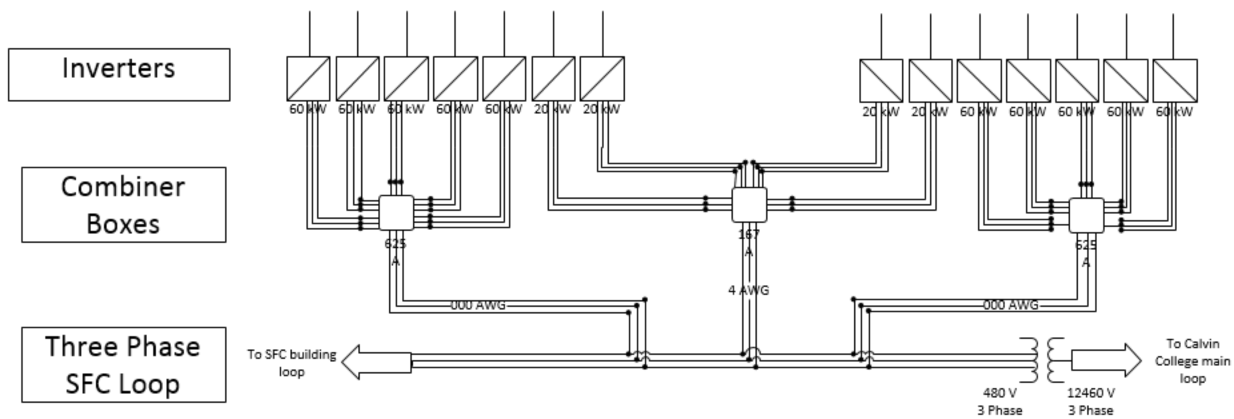


Figure 22: Power Grid Connection Diagram

A short summary of the costs associated with this option can be found in Table 17.

Table 17: Financial summary of Maximum Area option

Panels and Inverters	$ 1,272,115
Balance of System	$ 1,439,508
Labor	$ 639,768
Contingency (10%)	$ 207,927
Total	$ 2,287,204

9. Site Integration

a) Racking System

The Huizenga Tennis and Track Center's roof is constructed with a standing seam metal roof that is 24 inches on center. There are many options for attaching solar PV panels to a metal roof, but many require penetrating the roof. For this reason only two types of systems were considered. The first option was to use brackets that attach directly to the standing seam and then mount crossbeams made of a type of Unistrut. Another bracket would then be used to attach the panel to the Unistrut. The second option was to use a system that would just attach the panels directly to the standing seam. The first option uses brackets as shown in Figure 23 below that are already being used on the snow fences on the building. Most of the snow fences would be able to be removed if solar panels were installed and brackets removed from the fences could be used to attach the Unistrut to the standing seams.

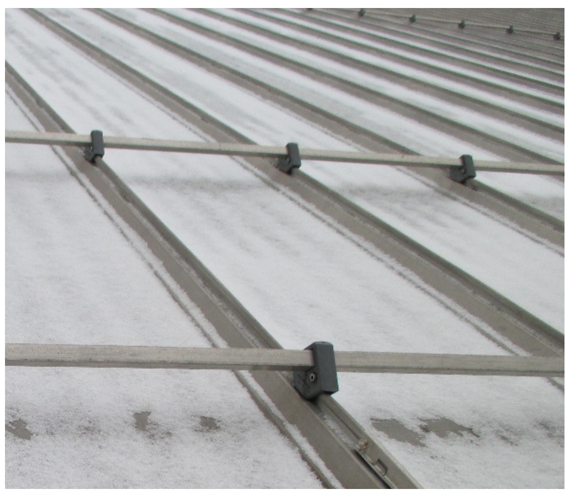


Figure 23: Option 1 Bracket (Photo Courtesy of Jack Phillips)

If only the bottom snow fenced were left on the both sides of the roof there would be a total of 640 brackets that could be reused. If installing a full size system, there would need about five times that amount of brackets. The second racking option is shown in Figure 24 below.

Figure 24: Option 2 Mounting System [10]

The bottom bracket is attached directly to the standing seam by a single set screw. The manufacture given allowable load with the standing seam roof is 700 lb. That means the connection between the bracket and the roof could withstand that load. Each panel is connected by four brackets and the system could withstand the most extreme weather conditions. The system shown above is made by S5, but is sold by several suppliers in the Midwest. Since the second option allows the brackets to be attached directly to the roof and did not require other crossbeams or support, it was selected as the recommended racking system. The recommended S5 system uses the S5-U mini clamp and the S5 PV Kit which combine to make the system shown above. The universal system shown above is used to attach two panels together and there is an edge grab system that would be used for the panels on the outer sides of the array. The frame is made out of anodized aluminum and the mounting disk is made from stainless steel. The weight of each complete bracket is 0.5 lb which is around 1.5 lb per panel. With the roof being 24" on center, it requires the panels to be mounted horizontally, meaning the long side of the panel would be perpendicular to the slope of the roof. The installation of these brackets is simple and is shown in Figure 25.

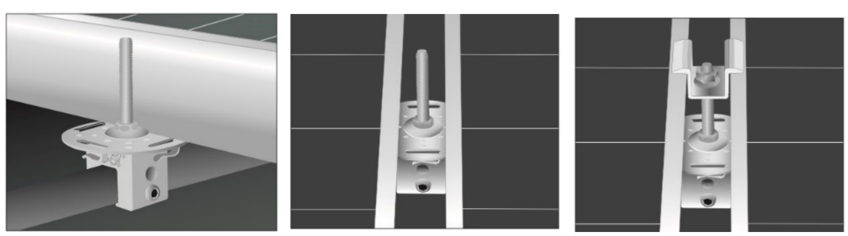


Figure 25: Installation of S5-PV Racking System [10]

The ridges in the standing seam roof are 3 inches above the trough and the S5-PV bracket adds another 1 inch. This allows the panels to sit 4" off the trough of the roof which will be sufficient to allow airflow under the panels. This is important because if solar panels overheat they will not perform as efficiently and can cause component failures. The cost of this system is around $0.09/watt or around $30 per panel which is very competitive with other mounting systems. Other systems such as the EcoFoot2, which was chosen for John Ball Zoo project, costs around $0.15/Watt or $50 per panel. Racking systems that involve tracks and brackets are closer to $150 per panel.

b) Safety

For workers to safely install a solar array on the roof the necessary safety precautions need to be taken, more specifically the fall safety precautions as specified by OSHA in code 1926.501 [11]. The code requires that there must be a safety system to protect workers from falling if they are working more than six feet above the ground. The two systems that the team looked at to meet the requirements were lifeline and metal roof railing systems.

i. Lifeline System

Horizontal lifeline systems are high tension steel lines that are run along the length of the roof (see Figure 26). Workers are then tethered to the line with a personal harness system which would catch them if they fell from the roof. These systems are an inexpensive solution but are really only beneficial if they are used for small work crews because of the weight restrictions placed on them. They can also be quite clumsy on a roof of such a large size because many horizontal lines would be needed to cover the roof due to tether length restrictions. The tether can be a maximum length of 30 feet as long as a worker couldn't free fall more than 6 feet off of any edge. This makes the layout of the lines very difficult and unaccommodating to the large number of workers who would need to be on the roof to install the array. Lastly with this safety system in play, students (or anybody else for that matter) would not be able to access the roof because users of the safety harness system need to be certified and own their own equipment. This would make the PV system lose a lot of its educational benefit. For these reasons it was decided that a safety railing system was to be pursued.

Figure 26: Safety Harness System [12]

ii. Railing System

The major plus side to having a railing system along the edges of the roof, is that it would be the only needed fall protection for the roof. It would have no restriction for the number of workers that could be using the roof at a given time. Also installers, maintenance workers, and students wouldn't need to be certified to use the roof.

The system the team looked at was a railing system designed by Simplified Safety. Designed for a standing seam roof, it attaches via clamps to the raised seams meaning once again no penetrations into the roof. It is also an aesthetically pleasing safety system as can be seen in Figure 27 below. Although it is a more costly solution than the lifelines, it is a safer option and one that will make the solar array more readily accessible to maintenance workers, students, and other interested parties. The railing will run the entire edge of the roof including the peaks which works out to be about 1040 linear feet. The price of the system is approximately $65,000 and is wrapped into the *Balance of System* line item in each design case.

Figure 27: Safety Railing System [13]

c) Monitoring

For any PV array monitoring software may be installed that allows the output of the system to be monitored and even controlled from a distance, depending on the software. Any monitoring system works in conjunction with the inverters. With monitoring software installed users can observe the output of the array through a mobile phone app, a webpage, or an access terminal; or any combination of these. The available display options and the information displayed by them is dependent on the software used. Possible information for display includes, but is not limited to power, current, voltage, sunlight, and the hourly, daily, yearly, and lifetime outputs of these.

Monitoring systems are available for purchase from Deck Monitoring, SMA Solar Technologies, Also Energy, and Consolidated Solar Technologies. Most options provided by these companies are customizable giving outputs from individual inverters and giving the option to make modification to the inverter software remotely. Most inverter manufacturers produce their own software that easily links with their inverters. Alternatively, Calvin Information Technology could be contracted to produce the software in house for $2000 for the SQL database and $4000 to set up the dashboard [14].

d) Equipment Placement

i. Inverter and Combiner Box Placement

The T&T has a utility room along the entire south wall. It is on the second story, above the storage rooms, offices, and bathrooms. The utility room holds the air handlers, LED lighting boxes, and other auxiliary components. Inverters will be mounted on wall racking with adequate space between each unit to allow for efficient heat dissipation. MLX 60 Inverters are 98.5% efficient. This means that electrical energy that is not converted from DC electricity to AC electricity is dissipated as heat. Table 18 shows the maximum possible heat production from the inverters in each case.

Table 18: Maximum Inverter Heat Generation

	Maximum Area	NetZero	500K
Power Generation [kW]	11.99 kW	10.07 kW	2.40 kW
Equivalent Electric Heaters	8	6	2

There are two primary options for combiner box placement: exterior mounting and interior mounting. Each has advantages and disadvantages.

If mounted on the exterior of the T&T, the combiner boxes would likely be placed at the peak of the roof. However, since the box dimensions are 20 x 20 x 6 inches, they would not fit underneath the solar panels. Therefore, panels would have to be removed to fit the panels at the peak of the roof. In addition, exterior mounting requires the boxes to be weatherproofed to protect the electrical components inside. Even so, the lifespan of the boxes could be reduced due to the element. Finally, if maintenance was required on the combiner boxes, then the maintenance worker would have to climb on the roof. This would not be comfortable working conditions during the winter, especially if the weather was snowy or icy. An advantage of this setup is that there are less wire losses from the individual solar arrays to each combiner box. In addition, it would require fewer and smaller penetration points, as only the combiner box output wires would have to be routed through roof conduits.

If mounted on the interior of the T&T, the combiner boxes would likely be placed on the I-beams that span the width of the T&T Figure 28. This location has several advantages. The mounting should be simple, as the boxes weigh 30-36 pounds and can be bolted directly to the beam. If the boxes require maintenance, then a scissor lift could be used to reach the box. This is much more comfortable for the workers, particularly in the winter months. However, Calvin College physical plant does not own a scissor lift big enough to reach the peak of the I-beams, so the boxes would have to be placed approximately halfway down the beam. This would result in larger wire losses than if the boxes were placed on the exterior of the building. The wires exiting the combiner boxes could then be strung down the remainder of the beam to the walls, where they could be routed to the utility room. This setup would require more and larger penetration points because the output wire from each string of solar panels would have to be routed through roof conduits.

Figure 28: T&T Interior

Interior mounting was chosen as the best option for the combiner boxes. The physical plant clients expressed that the comfort of interior maintenance was preferable to working on the boxes outside in the elements. In addition, the additional wire losses when mounting on the interior of the building are not significant enough to justify losing panel space.

ii. Roof Wiring and Penetration

The LG panels are built with 3 foot positive and negative DC cables. These cables are daisy-chained throughout a panel string and connected to a positive cable at one end and a negative cable at the other end of the string. Each of these positive/negative cable sets (one per string) will need to run from the ends of each string to the peak of the T&T building and penetrate through the roof to reach the combiner boxes. The DC cables on the roof will be made of approximately 10 gauge wire and will run along enclosed tracks throughout the array. The cables will enter conduit systems between the roof penetration points and combiner boxes in the interest of cable protection. These conduit lines will run from the inside peak of the building to the halfway up the roofing beams, upon which the combiner boxes will be located. The higher gauge cable from the combiner boxes will run to the lower corners of the ceiling and into the second floor utility room.

iii. Inverter Power Grid Connection

The inverters will be tied to the main power loop of the Spoelhof Fieldhouse Complex. Three phase power from the inverters will be combined to yield ideal current levels in combiner boxes similar to those used for the panel strings. Three phase cable runs will attach the combined inverters in the upstairs utility room of the T&T building to the access point in the complex's main utility room using cable sizes dependent on the maximum current from each set of inverters. The cable runs will be integrated into the circuit between the complex's 12,460V transformer and the main breaker panel, allowing power from the inverters to feed the power demand of the complex and into the main Calvin College power loop when the complex's demand is below the output of the inverters.

Figure 29: Inverter Location in T&T Utility Room (shown in blue rectangle)

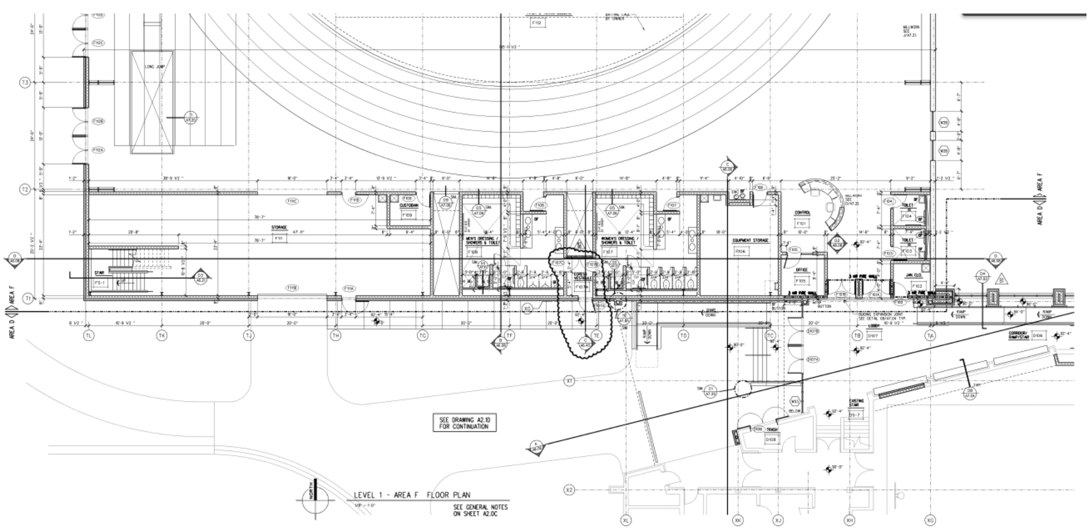


Figure 30: T&T Blueprint, Courtesy of GMB Architects and Engineers

e) Environmental Factors

i. Snow Load

The Huizinga Tennis and Track Center was designed to hold quite a bit of snow on its roof, as is typical of a Michigan design, but during the winter potential load on the roof could increase because of the array's weight. For the sake of time, the added stress due to the panel array was not calculated. Using the weights given in the design cases above, a certified structural engineer should verify that the roof can withstand the additional weight of the panels in addition to snow.

ii. Trees

The surrounding area of the Tennis and Track Center is relatively free of trees compared to other buildings on Calvin's campus. However, there is a small grove of trees on the east side of the T&T Figure 31. Using the Calvin Tree Map, which provides individual tree data including species, height range, condition, and replacement value, the effect of this grove on the T&T solar array was analyzed [15]. The trees on the west side of the T&T across the road were determined to be too far away from the roof to create a significant amount of shade on the solar panels. There are also a number of small, young trees and shrubs on the west side of the T&T along the building. However, these trees are short enough that they will not significantly impact power production within the lifespan of the panels.

The contents of the east tree grove are summarized below in Table 19. These trees represent a significant monetary investment of almost $53,000. If these trees were removed to eliminate the shade on the solar panels from the trees during the early morning hours, then new trees must be planted elsewhere on campus. This would add to the total cost of the project.

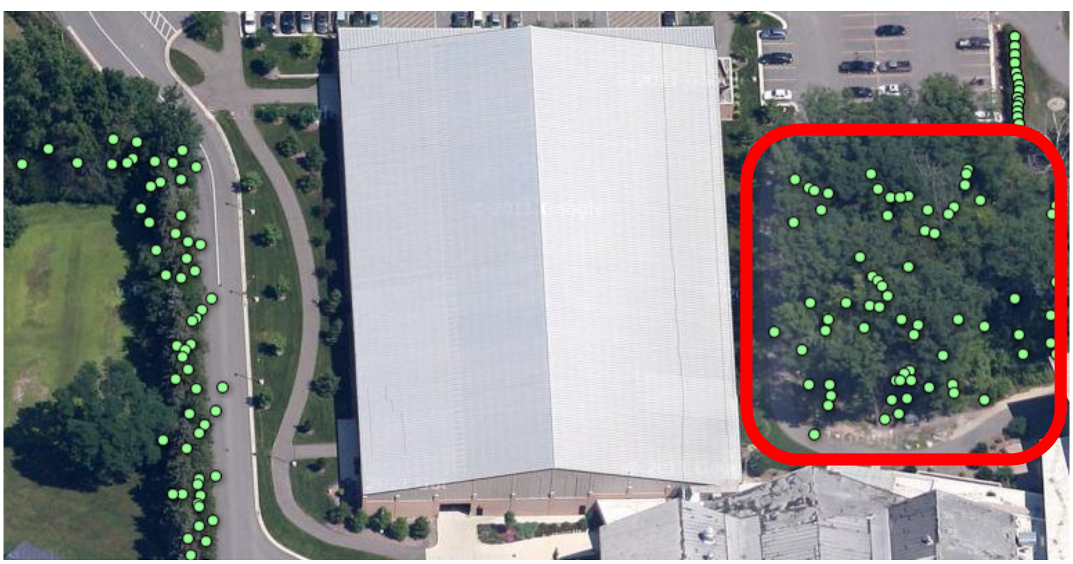


Figure 31: Tree grove on east side of T&T.

Table 19: Approximate tree composition of grove on east side of T&T [15]

Tree Species	Minimum Height [m]	Maximum Height [m]	Unit Replacement Value [$/tree]	Quantity	Total Replacement Value [$]
American Elm	9	16	472.74	2	945.48
Basswood	9	16	557.79	1	557.79
Basswood	9	16	1100.88	2	2201.76
Black Ash	9	16	538.42	1	538.42
Black Cherry	9	16	604.11	1	604.11
Blue-Beech	9	16	604.11	1	604.11
Red Maple	9	16	557.79	3	1673.37
Red Maple	9	16	1100.88	1	1100.88
Red Oak	9	16	1185.99	1	1185.99
Red Oak	9	16	1435.24	4	5740.96
Red Oak	9	16	2059.04	1	2059.04
Red Oak	16	24	3223.27	1	3223.27
Red Oak	16	24	4045.61	1	4045.61
Red Oak	16	24	5919.1	1	5919.1
Shagbark Hickory	1	9	457.52	3	1372.56
Shagbark Hickory	9	16	457.52	4	1830.08
Shagbark Hickory	16	24	457.52	1	457.52
Shagbark Hickory	9	16	853.75	4	3415
Silver Maple	9	16	899.45	1	899.45
White Ash	1	9	322.6	2	645.2
White Ash	1	9	519.06	1	519.06
White Ash	9	16	519.06	3	1557.18
White Ash	9	16	984.56	2	1969.12
White Oak	9	16	645.61	7	4519.27
White Oak	9	16	1310.61	1	1310.61
White Oak	16	24	1310.61	3	3931.83
			TOTAL	**53**	**52826.77**

10. Financial Summary

a) Method and Assumptions

The total project cost was computed by summing component costs and comparing to aggregate estimates for installation cost. The financial team consulted internet resources and solar contractors for estimates. Table 20 shows the assumptions that the financial team made in order to perform a fiscal analysis.

Table 20: Financial Assumptions

Cost of Electricity [$/kWh]	0.12
T&T Current Usage [kWh]	427,000
Installation [$/kW]	800
Contingency [%]	10
Electricity Escalation [%]	3.5
Effective Interest (discount rate) [%]	3
Shipping Rate [$/Panel]	6

Total project estimates were compared against aggregate data from the National Renewable Energy Lab, which shows that commercial-scale installations cost $2.50-4 per watt [16]. These benchmarks were crosschecked with two contractors who confirmed that installation depends largely on solar panel selection and ranges from $3-4 per watt.

i. Energy Usage and Rate Estimates

The energy usage of the T&T was estimated based on two 75 horsepower air handler units, LED lighting, and other auxiliary power requirements. For more detail, see Section 8. The rate was estimated based on a blend of Calvin's complex rate structure. Since solar arrays produce energy during the day, the estimated electricity rate was conservatively weighted toward the higher daytime rate.

ii. Interest, Escalation, and Inflation Rates

There is considerable debate among analysts concerning appropriate interest (discount) rates for renewable energy projects. The main concern surrounds opportunity cost and deciding what is the next best alternative for funds invested in solar PV. For projects financed with loans, an 8% discount rate is used based on standard investing returns. For government projects, 3% is used based on Treasury bond returns. For Calvin, an appropriate rate depends on what the alternative is. For simple comparison with other investing opportunities, the 4.5% endowment spend rate was used as a benchmark.

Inflation is extremely variable and applies to both electricity savings and cost of capital. Therefore, it is common practice to avoid inflation calculations by using nominal discount and escalation rates. The rate of energy cost escalation has historically been 3-4%, so a midrange estimate of 3.5% was used [17]. A higher escalation rate is advantageous for solar arrays because the cost of solar electricity is only affected by installation and maintenance costs.

iii. Installation Estimates

The installation estimate in Table 18 was given by Cascade Engineering in Grand Rapids, Michigan. The rate includes manual labor, electrician labor, and wiring material costs. This was a convenient method of estimation because material cost for wire was hard to approximate without a thorough analysis of the site.

iv. Material Estimates

Material costs were broken down into panels, inverters, combiner boxes, inverter control/monitoring systems, mounting, safety railings, and lightning protection systems. Each component's cost was confirmed through calls to contractors, internet searches, and aggregate data.

v. Shipping Cost

Shipping cost was estimated based on a free calculator at worldfreightrates.com. Based on 500 panels shipped from Los Angeles to Grand Rapids, a rate of $3000 for one truckload was converted to a per panel rate of $6/panel. This rate was scaled for all systems sizes.

b) Payback

For each of the three cases a feasibility study was done using a time value of money payback analysis. The chosen solar panels are warrantied for 25 years with a useful life of 40 years. Table 21 provides a precise summary of initial cost, the year when payback is achieved, average yearly savings, and the yearly spending rate. The yearly spend rate, calculated as average yearly savings over initial investment, is analogous to an endowment spend rate.

Table 21: Options Overview

	500K	Net Zero	Max Area
System Size [kW]	153	671	799
Initial Cost [$]	$498,872	$1,928,758	$2,287,204
Payback Time [years]	41	34	34
Initial Cost [$/W]	3.26	2.87	2.86
Average Yearly Savings [$/yr]	$12,452	$54,820	$64,978
Yearly Spend Rate [%]	2.50	2.84	2.84

The graph shown in Figure 32 presents the payback for each case. The average slope of each curve is the average yearly savings. The end of each curve represents the net present value of each option at the end of the useful life.

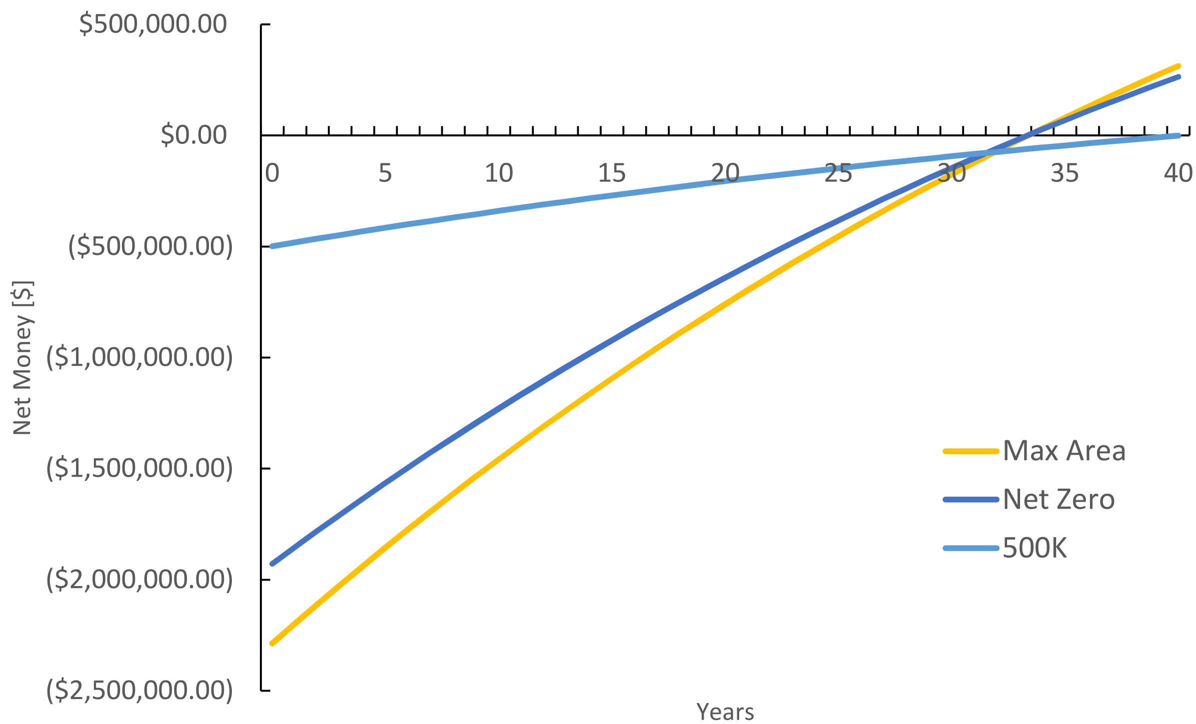


Figure 32: Payback at 4.5% Interest, 3.5% Energy Escalation

Based on the nominal assumptions, none of the options will have a payback period that is less than the warranty period. This is less than ideal because lifecycle testing on solar PV panels has been limited. While there are many aspects of the estimate which were conservative, such as a 10% contingency, the overall price estimate of the high cost options is below industry average of $3.5/W. This is not

c) Sensitivity Analysis

Estimates of payback are very sensitive to discount rate and energy production levels. Table 22 shows the wide variety of payback periods for the Net Zero option based on various estimates of energy production and discount rate. A discount rate of 0% is the federal rate used for non-energy capital projects, such as buildings.

Table 22: Net Zero Payback Sensitivity Study

	Payback Period [years]		
Discount Rate (%)	**Bunker Estimate**	**Average**	**Sunny Design Estimate**
4.5	Never	34	24
3	39	27	21
2	33	24	19
1	29	22	18
0	26	20	17

Figure 33: Payback of Net Zero Option at shows the broad range of payback periods and net present values for various discount rates. As the graph makes clear, solar PV is extremely profitable when viewed as an infrastructure improvement project with 0% discount rate. The curves presented are similar for the Maximum Area option.

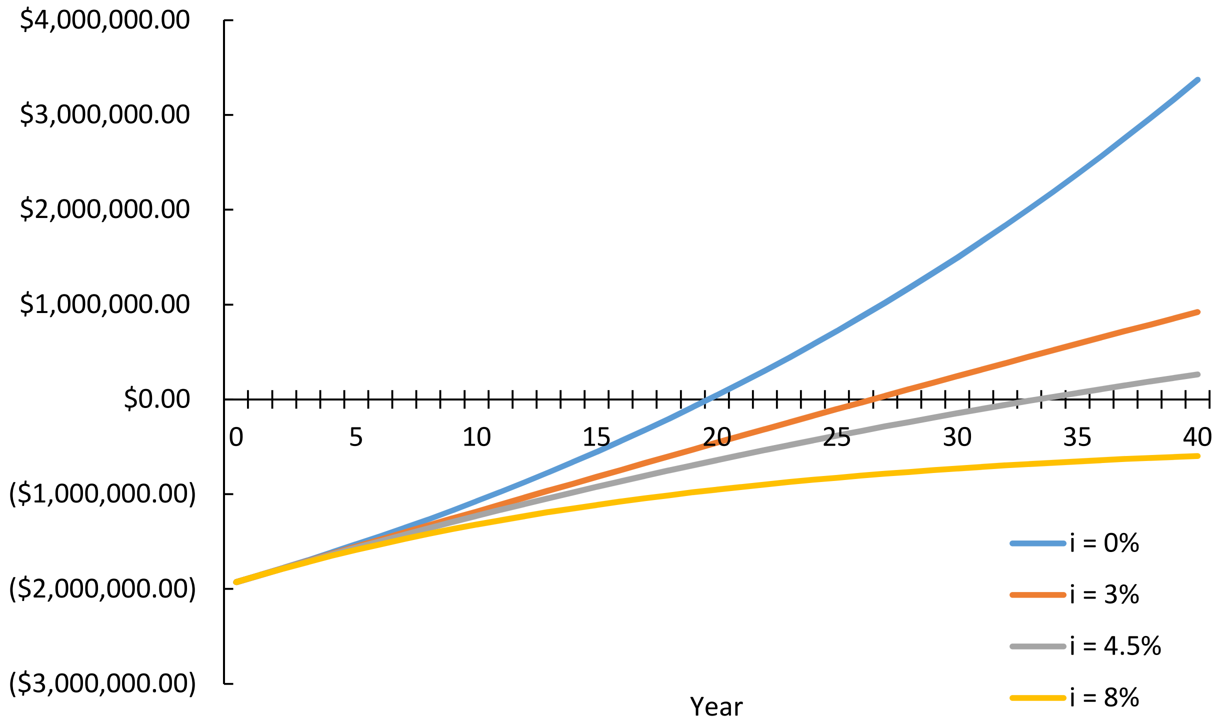


Figure 33: Payback of Net Zero Option at Various Discount Rates

The 500K option was also sensitive to energy production estimates and discount rate. Table 23 and Figure 34 demonstrate the sensitivity of the analysis.

Table 23: 500K Payback Sensitivity Study

	Payback Period [years]		
Discount Rate (%)	**Bunker Estimate**	**Average**	**Sunny Design Estimate**
4.5	Never	Never	29
3	Never	31	24
2	37	27	21
1	32	24	20
0	28	22	18

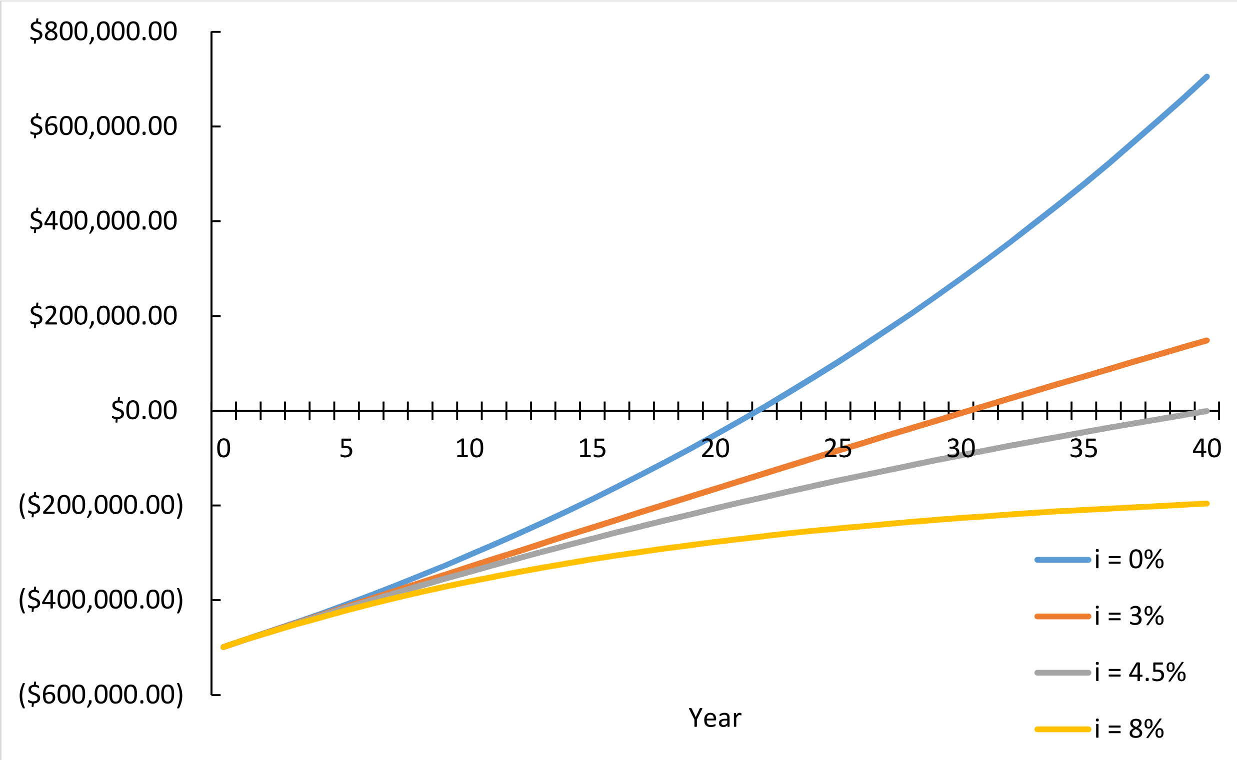


Figure 34: Payback of 500K Option at Various Discount Rates

d) Financing Options

According to information received from Jack Phillips and Chuck Holwerda, Calvin College would like to own the solar power system and utilize all of the energy produced. Ideally, all funding would come through donations and grants. Calvin's goals would eliminate the need for a power purchase agreements since most do not have a buyout option. The remaining options are direct financing, solar loans, and leasing. Figure 35 shows a comparison of return on investment for the 3 viable options.

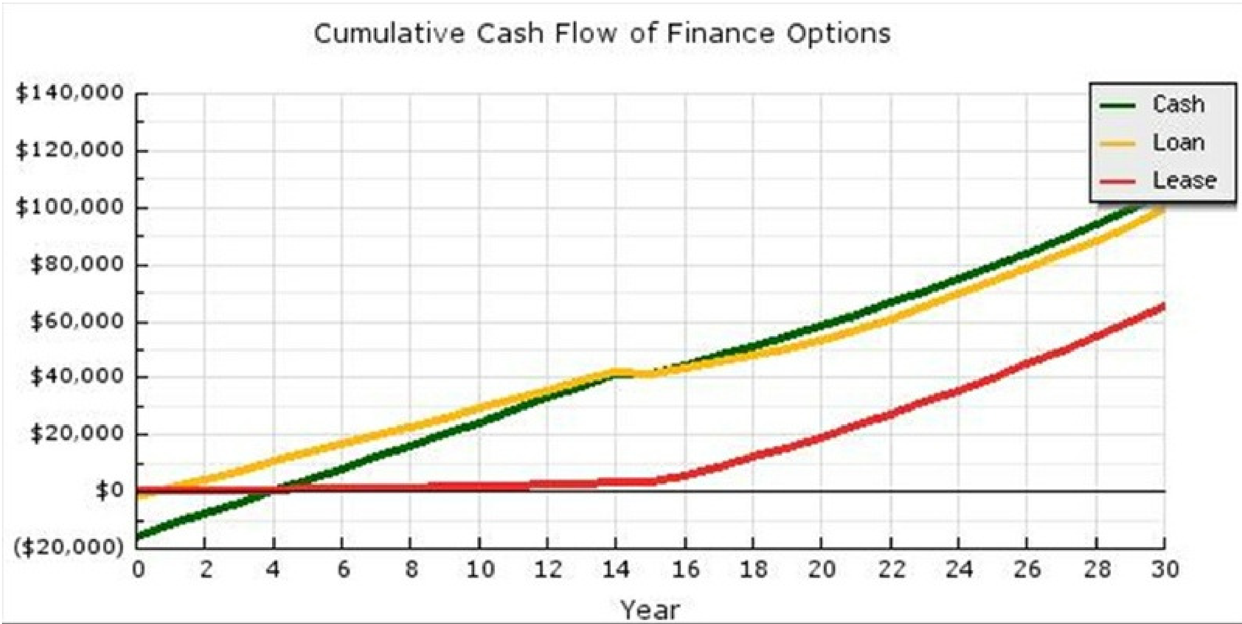


Figure 35: Finance Options Overview [18]

As seen above, solar leases provide the least amount of cumulative cash flow when compared to investing in a solar electric PV system via a loan or cash. Cash provides the highest return on investment due to the cost of capital ranging from 2-20% for loans and leases. Typical leases result in a 40% reduction in cash gained [18].

i. Direct Financing

There are many benefits for direct finance when an institution has available capital. With a donor-funded array, Calvin can immediately begin accruing energy savings without a loan payment. Additionally, solar panels can be depreciated using MACRS criteria; this is beneficial for solvency of the college. Figure 36 shows an estimate of cash flows to Calvin for donor-funded options.

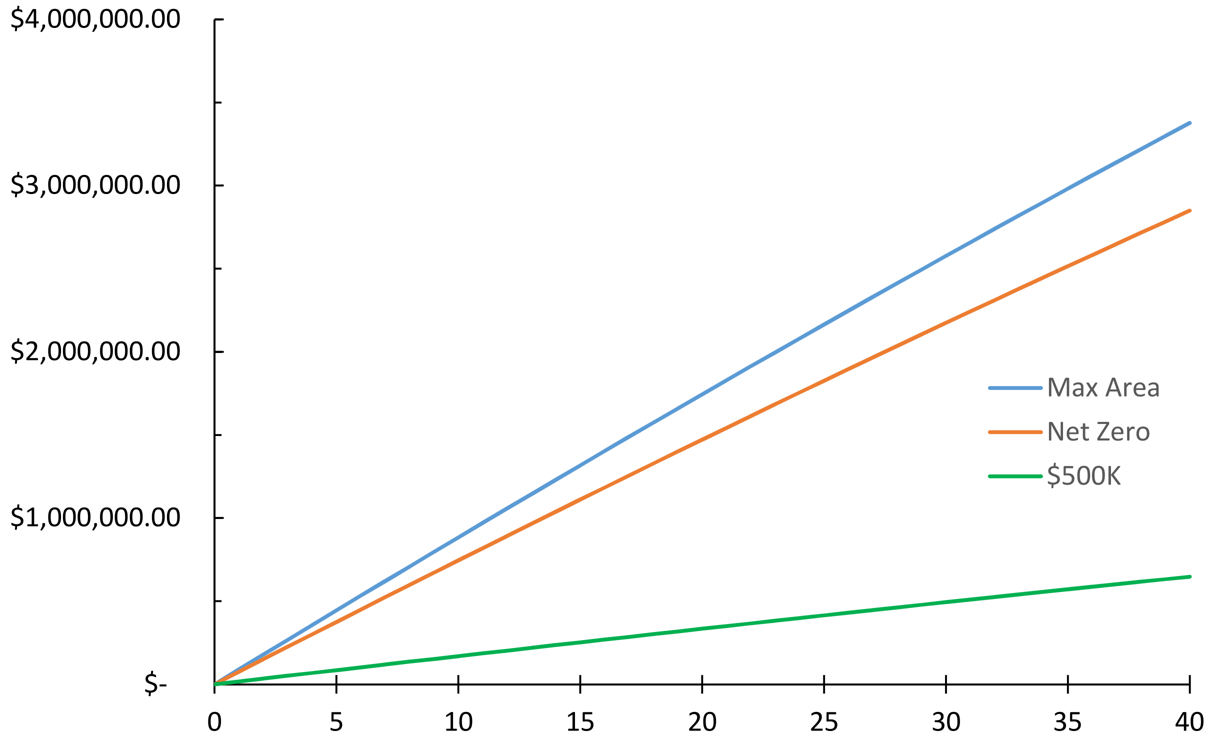


Figure 36: Donor Funded Cumulative Income

ii. Leasing

To lease solar panels, Calvin would agree to pay a monthly rate to a solar financing company for electricity produced from the solar array. The electricity rate, which can be fixed or variable, would be lower than the current cost of electricity. Under this agreement, there is no large upfront cost because the financing company installs and maintains the panels. Similar to donor funding, leasing would generate savings from day one. However, Calvin would only be able to claim renewable energy generation if the Renewable Energy Credits were purchased from the financing company. This makes marketing very difficult. More information on solar leasing can be found at the U.S. Energy Information Administration website [19].

iii. Grants, Rebates, and Incentives

At the moment, there are very few grants and rebates for non-profits organizations in the state of Michigan. Additionally, Calvin does not qualify for the generous federal tax credit of 30% which is available to all for-profit businesses and individuals.

iv. Temporary LLC

Calvin could take advantage of the tax credit by purchasing the system through a temporary LLC established in partnership with donors. Under this scheme, the donors would receive the federal tax benefit and then after 5 years donate the equipment and all but a small percentage of the tax credit to the college. This option is very attractive because of the federal tax benefit, but there are additional legal expenses and business licensure complications which could arise from pursuing this financing option.

e) Alternatives to Solar PV System

The key point of comparison for all capital expenditures is the next best alternative. For a solar array financed by donor funding, the next best alternative can take on many forms depending on how one views an investment in solar panels.

i. Energy Investments

One view is that solar panels are a prepayment on electricity for 25-40 years. In this case, the best alternative is an endowment account for electricity, similar to a scholarship. This is exactly the same analysis presented above with 4.5% interest. If the goal is to use renewable energy, then Consumers Energy will sell green energy for a $0.01/kWh surcharge. Renewable Energy Credits (REC) can also be purchase on the open market for $45-300/MWh [20]. Table 24 summarizes the net present value of five methods for spending the $2M donation for the Net Zero option. The values are negative because all of these are expenses.

Table 24. Alternatives to Solar PV System

Alternative	Net Present Value
Prepay (Endowment for Electricity)	-$1,769,499
Scholarship (Endowment)	-$1,769,499
Green Energy ($0.01/kWh surcharge)	-$1,916,958
Net Zero Solar PV System	-$1,928,759
RECs ($200/MWh and Electricity)	-$2,590,606

ii. Infrastructure Investments

Solar arrays can also be compared to infrastructure improvements, such as buildings and roads. For these type of improvements, little or no monetary payback is expected. For example, consider the Spoelhof Fieldhouse Complex. Completed in 2009 for $40M, administrators promised that a new building would draw students to Calvin. However, the cost of running the building effectively wipes out any gains from new students. A solar array could be seen as an infrastructure upgrade to the Calvin electric grid which secures the supply of electricity to the Tennis and Track center for the decades to come.

11. Marketing

The majority of this project, if approved, is expected to be funded by donors. Because it is a significant capital expenditure, an in depth marketing and fundraising campaign designed to raise the necessary funds for this project is necessary. The campaign consists of a general marketing strategy, market research, and marketing content necessary to promote awareness of the project to donors.

a) Marketing Strategy

There are a number of different marketing strategies in which to fundraise and increase awareness for the solar PV system for Calvin's campus. The use of informational videos, social media, "sell sheets", and crowdsourcing were the methods considered to be most effective for marketing this project. These approaches were then evaluated on the likelihood of donors giving money toward the project using the specific method. Categories such as age, potential revenue of the donor, and the ability of reaching donors were used in this evaluation, and the results of this assessment can be found in Table 25.

Table 25: Comparing Effectiveness of Methods of Fundraising to Demographic Traits

Characteristic	Videos	Social Media	GiveCorps	Sell Sheet
Age Group	All ages	Younger	Younger	Older
Potential Revenue	Low/Moderate	Low/Moderate	Moderate	High
Ability to Reach People	High	Very High	Moderate	Low

Using this table of as a reference, a decision matrix was created to discern which method of fundraising would be the most effective. The methods were rated on effectiveness against the marketing message that could be used for gaining donor funding. This table of effectiveness of the methods can be found in Table 26.

Table 26: Comparing Effectiveness of Methods of Fundraising and Selling Points

Messages	Videos	Social Media	GiveCorps	Sell Sheet
Sustainability	Very Good	Good	Moderate	Poor
Monetary Saving	Moderate	Poor	Good	Very Good
Energy Savings/ Emission Reduction	Moderate	Poor	Very Good	Good
Stewardship	Moderate	Poor	Good	Very Good
Student Opportunities	Very Good	Good	Moderate	Moderate
Focus Rating	3.4	1.4	2.8	2.8

The results of this table show that the informational videos can be a major marketing tool, having the capability of referencing and giving information on all the messages being communicated, in addition to the high reachability to donors. The sell sheet and GiveCorps site are also an effective way to market this project, especially when considering that videos can be put on the GiveCorps site. Moving forward, video production, sell sheets, and the GiveCorps should be heavily implemented to fund this project.

b) Market Research

Market Research was conducted using a dataset provided by Calvin Development. By analyzing trends in donor giving, the marketing strategy was confirmed to be an effective plan to reach donors. While most funds are given by relatively few donors, the majority of donations occur in small amounts. Therefore, balancing both sell sheets and crowdsourcing materials is an ideal strategy to reach all potential opportunities for fundraising.

Additionally, the majority of donors have some level of technical experience, based on their degree type. Therefore, most marketing material should be friendly towards donors who understand both technology and business. A key selling point will be that a design has potential to make the Tennis and Track Center Net Zero, which has significant technical and economic benefits.

c) Fundraising Financial Forecast

Given past donor data, it was predicted that $80,000 could be raised from the GiveCorps website and $400,000 from traditional fundraising techniques. This is why there is the $500,000 project budget for the small design case. Anything beyond that will come from other areas of the Calvin budget, such as physical plant.

d) Marketing Cost

In the communications with Calvin Development, it was estimated that a project of this size would use about 20 hours of work to successfully market. This would most likely be for generating content and reaching out to donors. $50 per hour for the marketing rate was an agreed upon figure which could be used for the cost of marketing. With this rate and time, a marketing budget of about $5,000 is assumed for the project.

e) Donor Sell Sheets

These sheets are meant to be given to donors during one-on-one visits with larger donors. They contain relevant information related to the project including costs, savings, impacts, and previous related projects. The donor sell sheet created can be seen in Appendix B.

f) GiveCorps Website

The GiveCorps website is similar to Kickstarter in that it is a crowd-funding website. It allows for individuals to easily contribute financially to this project on a small scale. The website includes information about the project, how it's relevant, how solar panels work, and more. It was put together by students in collaboration with the Calvin College Development.

g) Marketing Video

High quality video drastically increases the success of crowd funding initiatives. A preliminary marketing video has been created, showcasing important footage generated while the system was designed. Additional videos should be produced to showcase student, economic, and environmental benefits, which can be displayed on the GiveCorps website and shared through social media.

12. Recommendation

We recommend that Calvin install the Net Zero PV system using direct financing. Although this route has significant up front cost, it saves more money in the long term and Calvin will have complete control over all aspects of the solar PV project. Calvin is in a good position to obtain a large portion of the capital cost from donors who are interested in sustainability and fiscal responsibility.

In light of ongoing master planning activities and the recently approved strategic plan, we recommend that this solar array be considered as an infrastructure upgrade which reinforces Calvin's commitment to environmental responsibility. Furthermore, it is a sound financial practice to lock in electricity rates in the T&T for the next 25 years using a fixed cost solar PV system.

However, after completing the feasibility study for this project, we have discovered that the paybacks are not as appealing as desired. We propose that Calvin use three years for fundraising before installing a Solar PV system to allow time for installation costs to decrease. Figure 37 shows aggregate trends for installation costs from the National Renewable Energy Lab (NREL), which is the preeminent source of data in this domain. In the next 5 years, the open market is expected to exhibit considerable pressure on contractors to install solar arrays at lower cost.

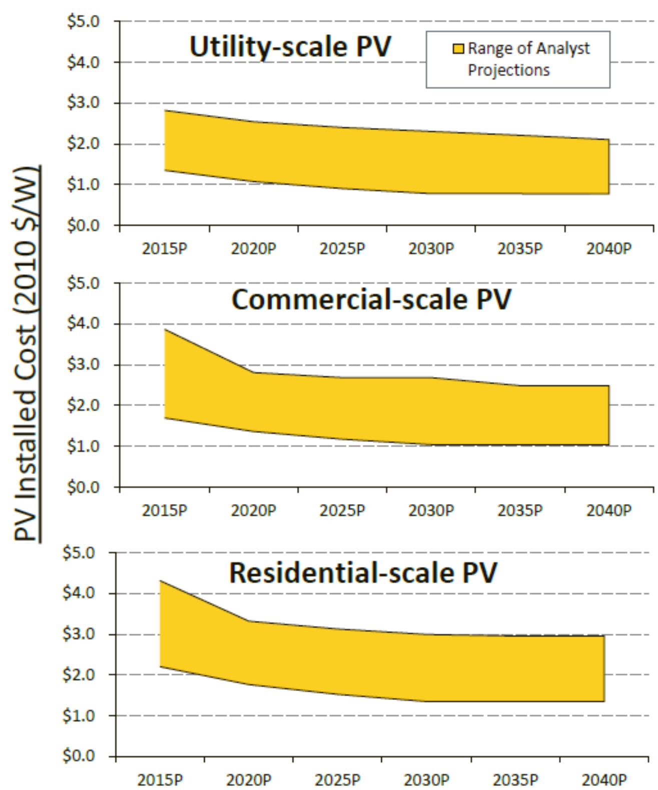


Figure 37: NREL Projections for Solar PV Installation Costs [16]

If insufficient funding is available, we suggest the 500K option. However, understand that upgrading from a 500K option to a Net Zero option cannot be completed at a later date without funds beyond the cost differential for extra transmission capacity to the main Calvin grid. If an upgrade is anticipated, future financial burden can be avoided by installing capacity for the maximum area option from the onset.

13. Acknowledgements

The students of Engineering W80 would like to thank the following people and companies for their contribution to the success of this project:

Matthew Heun, Professor at Calvin College

Gayle Ermer, Professor at Calvin College

Professors Heun and Ermer worked effectively and patiently to ensure their students would be prepared for the solar projects. They were available for input and assistance whenever a team required it, offering sound information and exypertise.

Jack Phillips, Assistant Mechanical Director at Calvin College Physical Plant

Jack took time out of his schedule to sit in on class presentations and offer useful input whenever appropriate. He was willing to drop whatever he was doing to answer questions in a friendly and frank manner.

Dan Slager, Energy Management Technician at Calvin College Physical Plant

Dan offered his insight into the Spoelhof Fieldhouse Complex's electrical system, helping the panel and inverter team to produce an appropriate plan to tie into the school's electrical loop. He was willing to do this on a Friday at 4:30 PM, when most people have better things to do.

Chuck Holwerda, Electronic Shop Technician at Calvin College

Chuck took the time to give a detailed presentation on solar power technology and Sunny Design software to the entire ENGR-W80 class. He welcomed several different task forces into his office to answer detailed questions and provide useful suggestions for the solar project.

Eric Kamstra, Assistant Director for Alumni and Annual Giving at Calvin College

Amanda Greenhoe, Writer and Social Media Manager at Calvin College

Both Eric and Amanda were incredibly helpful regarding marketing and fundraising information. They helped to provide us a non-technical way to view this project, and both were willing to help guide marketing strategy, as well as help with website and sell sheet development.

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15. Appendix A: Bill of Materials

Table 27: Bill of Materials for 500K Case Using LG Panel

Description	Sub-Assembly	Quantity	Unit Price [$/Unit]	Cost [$]
LG300N1C-G3	Panels	500	$433.00	$216,500.00
SMA MLX 60	Inventers	2	$11,320.31	$22,640.62
STP 12000TL	Inverters	1	$4,852.00	$4,852.00
SolarBOS CDK-08-15-N4	Combiner Boxes	3	$325.14	$975.42
SMA CLCON-10 Cluster Controller	Inverter Ctrl/Monitor	1	$1,540.35	$1,540.35
Racking System - S5! Mini Ribbed Profile	Mounting	500	$29.40	$14,700.00
Safety System - Railing	Safety	1030	$65.00	$66,950.00
Chinti OBV5-C40	Lightning Protection	2	$85.00	$170.00
Delta MO603	Lightning Protection	3	$64.00	$192.00
Shipping	Whole System	1	$3,000.00	$3,000.00
			Subtotal	$331,520.39
Labor Cost	-	1	$122,000.00	$122,000.00
			Total	$453,520.39

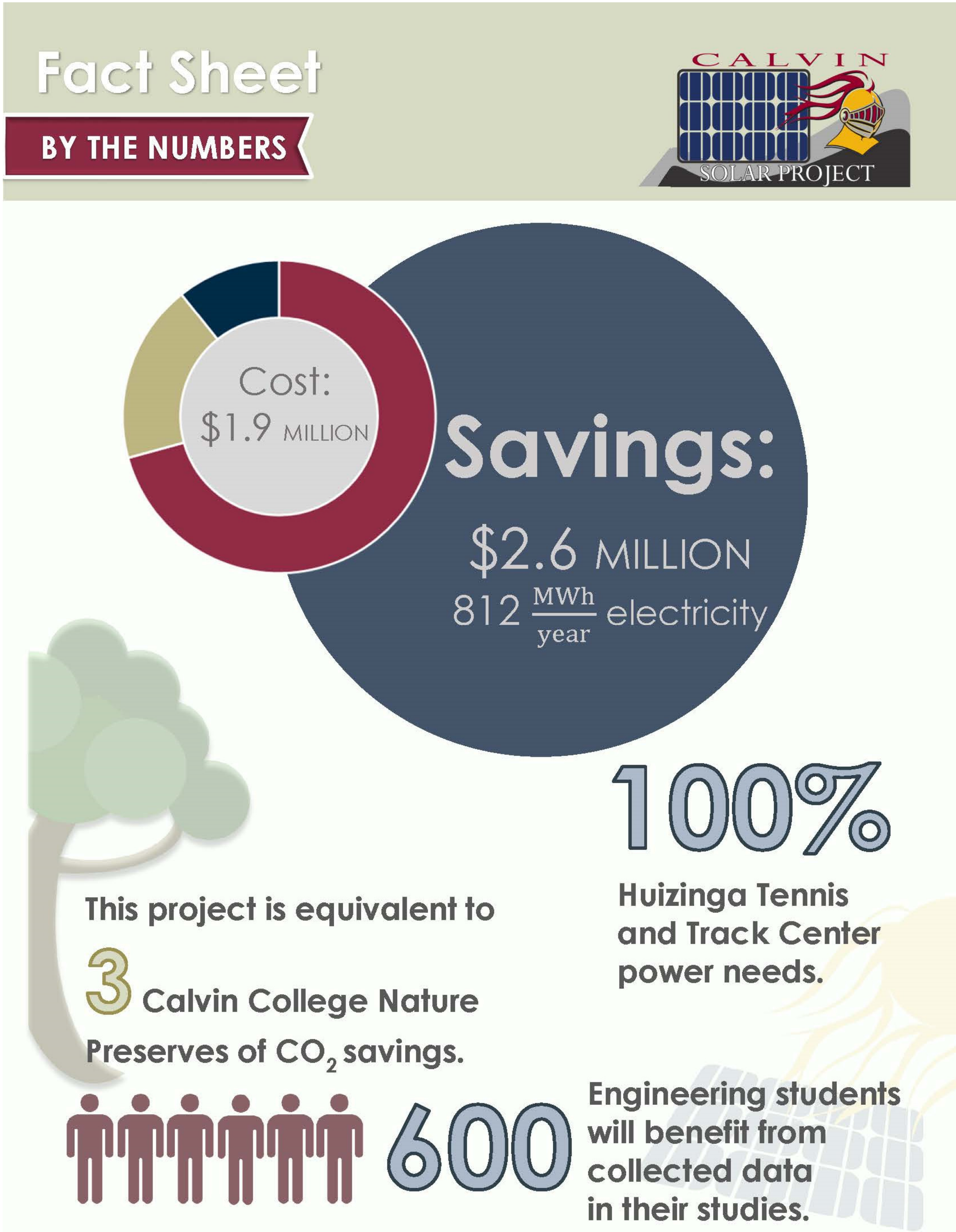
Table 28: Bill of Materials for Net Zero Using LG Panel

Description	Sub-Assembly	Quantity	Unit Price [$/Unit]	Cost [$]
LG300N1C-G3	Panels	2200	$433.00	$952,600.00
SMA MLX 60	Inventers	10	$11,320.31	$113,203.10
SolarBOS CDK-08-15-N4	Combiner Boxes	10	$325.14	$3,251.40
SMA CLCON-10 Cluster Controller	Inverter Ctrl/Monitor	1	$1,540.35	$1,540.35
Racking System - S5! Mini Ribbed Profile	Mounting	2200	$29.40	$64,680.00
Safety System - Railing	Safety	1030	$65.00	$66,950.00
Shipping	Whole System	1	$150.00	$150.00
Chinti OBV5-C40	Lightning Protection	10	$85.00	$850.00
Delta MO603	Lightning Protection	3	$64.00	$192.00
Shipping	Whole System	1	$13,200.00	$13,200.00
			Subtotal	$1,216,616.85
Labor Cost	-	1	$536,800.00	$536,800.00
			Total	$1,753,416.85

Table 29: Bill of Materials for Max Area Using LG Panel

Description	Sub-Assembly	Quantity	Unit Price [$/Unit]	Cost [$]
LG300N1C-G3	Panels	2622	$433.00	$1,135,326.00
SMA MLX 60	Inverters	10	$11,320.31	$113,203.10
STP 24000TL	Inverters	4	$5,896.61	$23,586.44
SolarBOS CDK-08-15-N4	Combiner Boxes	14	$325.14	$4,551.96
SMA CLCON-10 Cluster Controller	Inverter Ctrl/Monitor	1	$1,540.35	$1,540.35
Racking System - S5! Mini Ribbed Profile	Mounting	2622	$29.40	$77,086.80
Safety System - Railing	Safety	1030	$65.00	$66,950.00
Shipping	Whole System	1	$150.00	$150.00
Chinti OBV5-C40	Lightning Protection	14	$85.00	$1,190.00
Delta MO603	Lightning Protection	3	$64.00	$192.00
Shipping	Whole System	1	$15,732.00	$15,732.00
			Subtotal	$1,439,508.65
Labor Cost	-	1	$639,768.00	$639,768.00
			Total	$2,079,276.65

16. Appendix B: Sell Sheet



Solar Panel Array

Helping Calvin College to become better stewards of money, energy and resources.

BACKGROUND

Calvin College has been investing in the reduction of energy consumption on Campus for a number of years. With the help of donors, Calvin College plans to expand these efforts by installing a solar array. By harnessing the power of the sun, a solar array located on the Huizenga Tennis and Track Center will provide clean power to the building, saving both money and energy.

Calvin's push for energy efficiency has decreased the amount of costly resources used, helping the college to better answer the God's call to become stewards of His creation. A solar array will further this goal, using natural resources responsibly and promoting environmental responsibility. By implementing renewable technologies such as solar panels, Calvin can reduce its carbon footprint, lowering the harmful CO_2 emissions that are causing our climate to change.

Interior View of Huizenga Tennis and Track Center

Implementing a solar array for the Huizenga Tennis and Track Center will produce significant monetary savings from the energy generated. This technology has already been implemented on Calvin's campus at the Bunker Interpretive Center, but only as a learning tool. The proposed Huizenga Tennis and Track Center solar array will be a large scale installation, offsetting a substantial amount of Spoelhof Fieldhouse complex's electric needs. The money Calvin College saves by producing electricity from solar panels rather than purchasing it will then be channeled into efficiency projects elsewhere on campus, furthering the energy savings of the college.

Educational opportunities for future students will also arise from the installation of this solar array. Students will directly benefit from having the ability to interact with the solar array. Learning about energy efficiency, the lowering of carbon emissions, stewardship, and sustainability will be a major benefit for students.

Your gift will help to accomplish:

- Saving money by reducing energy costs for the college.
- Reduced emissions through the use of renewable technologies.
- Promotion of environmental responsibility and increase energy efficiency.
- Reduced dependence on variable-cost fossil fuel consumption.

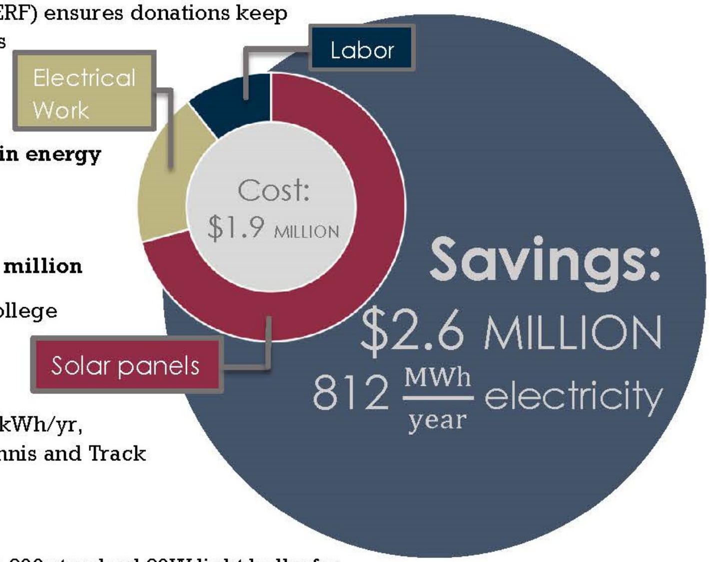
"The solar panel project fulfils Calvin's strategic plan by promoting environmental responsibility. Additionally, the student opportunities possible by this project will benefit Calvin for years to come.."

—John Sherwood, CERF Intern

MONETARY & ENERGY SAVINGS

Provides positive return on investment, benefiting Calvin for years to come:

- Savings from reduced electric bills will be larger than the cost of implementing the project.
- Calvin Energy Recovery Fund (CERF) ensures donations keep giving through the revolving funds



39,000 ft^2 of solar panels saves $75,000 in energy costs every year.

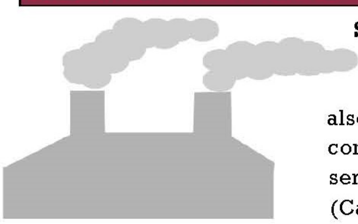
Full project implementation costs $1.9 million

- 100% of savings goes to Calvin College

Energy Savings:

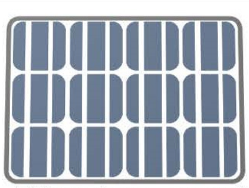
- This project will produce 812,000 kWh/yr, meeting 100% of the Huizenga Tennis and Track Center power needs.
- This is enough power to run over 4,600 standard 60W light bulbs for 8 hours every day. This means the energy from the solar array could power a desk lamp for every on-campus student to use while studying.

EMISSION REDUCTION & SUSTAINABLITY



Stewards of Creation:

"The Reformed tradition recognizes the important role of creation as God's general revelation of goodness and grace. We also recognize our responsibility to interpret, wisely use, and compassionately care for God's creation. In doing so, we take seriously the Biblical mandate to be stewards of God's good earth." (Calvin College Statement on Sustainability)



- In 2009, less than 1% of Michigan's energy came from solar panels (energy.gov).
- The carbon sequestration provided by this project is equivalent to 3 Calvin Nature Preserves (www.epa.gov).

This project supports the Calvin 2019 Strategic Plan in the areas of Strengthen Calvin's Mission in Education, Secure Calvin's Mission in Scholarship, Secure Calvin's Financial Future, and Promote Environmental Responsibility

FUTURE STUDENT RESEARCH

Generates data usable for research and projects.

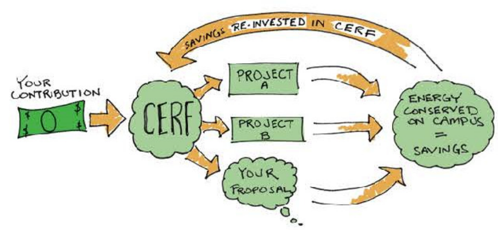
- More than 600 Engineering students will be able to study power generation data over the lifespan of the solar panels.
- This data can be compared to generation data from the Bunker Interpretive Center's solar array and the Calvin College Demonstration Wind Turbine to seek relationships and improve solar generation prediction.
- A large scale solar implementation helps students grasp the potential of renewable energy systems by giving students hands-on opportunities to interact with a large scale solar array.
- The system was designed in part by a group of senior engineering students during the month of January, 2015.
- The renewable energy industry expected to grow. The hands-on experience that this system will provide to Calvin students makes them a leader out of college.

Data from Calvin College Demonstration Wind Turbine being analyzed by engineering students.

INVESTMENT AND IMPACT

The savings from this project will be put into the Calvin Energy Recovery Fund (CERF). CERF is a revolving fund used to improve energy efficiency and reduce carbon dioxide emissions on campus. The cost savings from CERF projects are routed back into the fund for five years after project payoff, thereby growing the fund to support future projects.

Therefore, any money invested into this project will continue to be invested for years to come.



Investment	Impact
$2.2 M	Stretch goal: Implement Solar panels to power the entire Huizenga Tennis and Track Center with extra savings for at least 25 years. Net projected savings in energy bills: $2.6 million.
$1.9 M	Implement Solar panels to power the entire Huizenga Tennis and Track Center for at least 25 years. Net projected savings in energy bills: $2.2 million.
$500,000	Powers the lights in the entire Huizenga Tennis and Track Center for at least 25 years. Net projected savings in energy bills: $575,000.
$500	Buys and installs 1 panel, including all necessary components. Net projected savings in energy bills from each panel: $1000.

A dollar given now will save Calvin College many dollars in the future. This project, by saving energy, creates a system of automatic gift matching from your donation.

17. Appendix C: Quotes

OAK ELECTRIC.COM
Delivering energy in every way

5492 Dixie Hwy
Waterford, MI 48329

Ph: 800-964-7070
Fax: 248-623-4911

Photovoltaic Estimate

DATE: January 27, 2015
INVOICE: 992788

1MEG

** THIS PROPOSAL IS ONLY VALID FOR 15 DAYS **

Customer Information	
Calvin College	
sample quote only	
sample quote only	
sample quote only	
Annual kWh Usage:	Unknown
Utility Provider:	Consumers

System Details			
Panels	Sunpower-345NE-wht-D		
Wattage	345	**Efficiency**	20.0%
Inverter(s)	Exclusive Sunpower Inverter		
Mounting	SunPower		

PROJECT DESCRIPTION:	**1000.500**	**kW**	**Roof mounted array**
Current kWh rate:	**1,152,576**	**Expected annual solar production kWh**	
0.14	**$ 0.114**	**cost per kWh for solar power**	

Investment Information		
Initial system cost	$	4,684,211.00
30% Federal Tax Credit	$	1,405,263.30
TOTAL PROJECT COST	$	3,278,947.70
Annual REC payment @ 0.02	$	23,051.52
Energy savings & net meter	$	161,360.64

Unique System Exclusives
25 yr Full product & labor warranty (piece of mind)
Sunpower Panels (worlds most efficient)
25 yr Performance warranty (highest reliability)
High Efficiency Sunpower Inverter (more power)
Oak NABCEP Certified Installation (most experience)

This proposal is preliminary pending technical pre-inspection, final pricing may vary.
REC pricing can not be guaranteed
Oak Electric does not guarantee system preformance and REC pricing.
Price Includes all materials, labor, engineering, utility paperwork, design and consultation.

Your Estimated Energy Savings		
Monthly savings & REC $	$	15,367.68
1 yr savings & REC $	$	184,412.16
5 yr savings & REC $	$	1,216,086.91
10 yr savings & REC $	$	2,805,718.82
15 yr savings & REC $	$	4,919,266.96
25 yr savings and REC $	$	11,133,408.87

System pays itself off in **12.3** **yrs**

Annual Return on Investment **9.58%**

5492 Dixie Hwy. Waterford, MI 48329 Phone: 800-964-7070 oakelectric.com

Photovoltaic Estimate

OAK ELECTRIC.COM
Delivering energy in every way

5492 Dixie Hwy
Waterford, MI 48329
Ph: 800-964-7070
Fax: 248-623-4911

DATE: January 27, 2015
INVOICE: 948472

900kw ** THIS PROPOSAL IS ONLY VALID FOR 15 DAYS **

Customer Information	
Calvin College	
sample quote only	
sample quote only	
sample quote only	
Annual kWh Usage:	Unknown
Utility Provider:	Consumers

System Details			
Panels	LG, Solarworld, Suniva		
Wattage	250	**Efficiency**	15.7%
Inverter(s)	Grid Tie Inverter		
Mounting	Unirac		

PROJECT DESCRIPTION:		**893.750**	**kW Roof mounted array**
Current DTE kWh rate:		**972,400**	**Expected annual solar production kWh**
0.14	**$**	**0.067**	**cost per kWh for solar power**

Investment Information		
Initial system cost	$	2,320,114.00
30% Federal Tax Credit	$	696,034.20
TOTAL PROJECT COST	**$**	**1,624,079.80**
Annual REC payments	$	48,620.00
Energy savings & net meter	$	136,136.00

Unique System Exclusives
10 yr Full product & labor warranty (piece of mind)
25 yr Performance warranty (highest reliability)
High efficiency transformerless inverter (more power)
Oak NABCEP Certified Installation (most experience)
North American made solar equipment

This proposal is preliminary pending technical pre-inspection, final pricing may vary.

Oak Electric does not guarantee system preformance and REC pricing.

Price Includes all materials, labor, engineering, utility paperwork, design and consultation.

Your Estimated Energy Savings		
Monthly savings & REC $	$	15,396.33
1 yr savings & REC $	$	184,756.00
5 yr savings & REC $	$	1,025,982.62
10 yr savings & REC $	$	2,367,116.04
15 yr savings & REC $	$	4,150,264.76
25 yr savings and REC $	$	9,393,835.13

System pays itself off in **7.4** **yrs**

Annual Return on Investment **19.14%**

5492 Dixie Hwy. Waterford, MI 48329 Phone: 800-964-7070 oakelectric.com

Balance of System Products for the Solar Energy Industry
310 Stealth Court, Livermore CA 94551 tel: 925.456.7744 fax: 925.456.7710

Quote Number: Q15-20223
Date Quoted: 01/20/2015

CUSTOMER
Calvin College
,
Attn:
Email: twbrown525@gmail.com

We want to serve you more efficiently.
Please include the SolarBOS QUOTE and PART numbers on your PO
Thank you for your business

	PROJECT NAME	SALES ASSOCIATE
	TNT Solar Array	Alexander Stonich

ITEM	PART NUMBER DESCRIPTION	QTY	EACH	TOTAL
1	CS-12-15-N4 600 VDC Combiner per the following specifications (listed to UL-1741): 1) 16x12x6" NEMA-4 powder coated steel enclosure 2) 12 x 15 Amp fuses 3) 12 Ungrounded input touch-safe fuse holders, terminals sized to accommodate #14-8 conductors 4) 12 Grounded input terminals to accommodate #14-8 conductors 5) 1 x Ungrounded output terminal(s) to accommodate #6-350 MCM conductors (Mechanical lug) 6) 1 x Grounded output terminal(s) to accommodate #6-350 MCM conductors (Mechanical lug) 7) PE Ground terminals sized for 8 x #14-6 and 3 x #14-1/0 conductors	48	$325.24	$15,611.52
			TOTAL FOR QUOTE (USD):	**$15,611.52**

Please Note: Non-Standard Products including custom solutions and ReCombiner line are subject to Non-cancelable/Non-returnable conditions under SolarBOS Terms and Conditions.
This quotation does not include taxes or shipping costs.
All prices are in US Dollars.
All shipments are FOB Origin, unless otherwise explicity noted.
All fuses are included in pricing and ship installed with combiners unless otherwise noted.
Quotation is valid for 90 days.