REHOBOTH SOLAR PROJECT
FINAL REPORT

Calvin College

Engineering W83-A
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Introduction

During the 2014 Interim, the Engineering W83 class was asked the question, "what would it take for the Rehoboth Christian School in New Mexico to construct, own, operate, and maintain a solar photovoltaic (PV) energy system?" This question was divided into four main sections, including:

- An analysis of the site capabilities and optimum PV system location
- An analysis of the optimum PV panels for this system, with mounting considerations
- An analysis of the optimum inverters for this system, with a utility interface
- An analysis of the financial requirements and financing options for this system

The design and research described below proposes an environmentally sustainable and cost-effective method for integrating a solar photovoltaic system on the campus of Rehoboth Christian School.

After initial communication with Jeff Banaszak, the director of operations at Rehoboth Christian School, the team decided to aim for a system that would offset approximately 50% of the annual energy consumption. The team also gathered that one goal of this project was to reduce the direct involvement and responsibility by Rehoboth, as they express the statement that their primary objective is to educate students, and not operate as a power company.

Procedures

The execution of this project was accomplished by dividing the class into four teams, with a representative from each group to coordinate all activities among the groups plan the final report and presentation. A listing of each team and their primary accomplishments are as follows.

- Site
  The site team focused its efforts on obtaining possible locations for the implementation of a solar PV system. Along with finding locations, the team spent time trying to understand the culture in Rehoboth to avoid any conflicts with the community. The site team also looked into the roof materials of each location along with specific mounting options that would be compatible.
- Panel
  The panel team performed detailed research with regard to modern photovoltaic solar panel technologies. In doing so, the team was able to narrow their selection down to five different panels from three different manufacturers. Sunny Design software was used to calculate the necessary number of panels based on the location of the Rehoboth Community, while also factoring in weather and other geological conditions. The team collaborated with the site team and the inverter team to configure the best scenario in terms of panel layouts. The team then implemented this design into a 3-D Google Sketchup model of the Rehoboth Community.
- Inverter
  The inverter team preformed detailed research regarding solar PV inverters. The team also did extensive research regarding the gird-tie and net-metering requirements for the system to be connected to Gallup Joint Utilities, the electricity provider for the Rehoboth Community. They also researched solar system monitoring systems. The team collaborated with the panel team to design how the solar panels would be connected to each other in strings and how these strings would be connected to the inverters. They also collaborated with the site team to determine the optimum locations for inverter mounting.

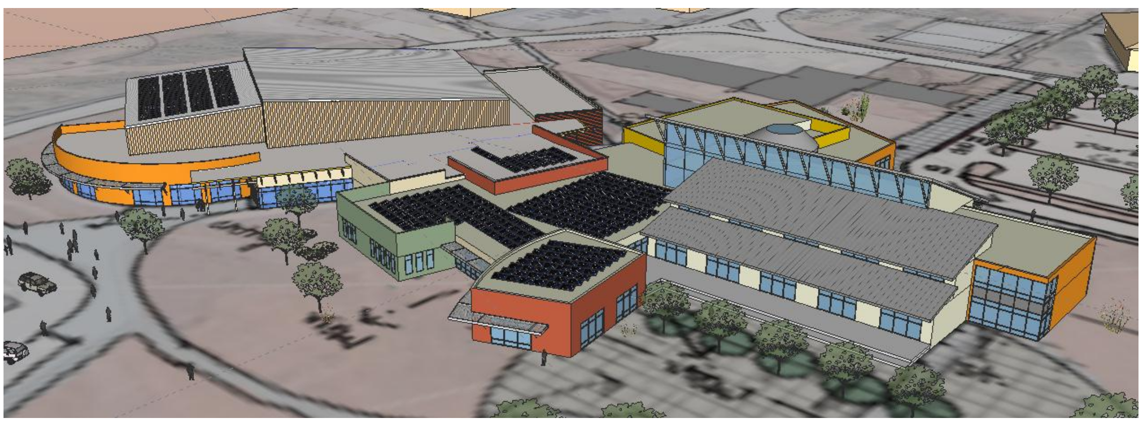
- Financial
  The financial team researched possible grants and incentives for solar PV systems. Different financing options were also researched. Rehoboth's electric bills from Gallup Joint Utilities were also analyzed to determine the sizing of the system and research was done rates and tiers available from this power company. A spreadsheet was created in order to combine and analyze inputs from the other teams.

Data

Data and supporting research for each team is located in their appropriate sections. Appendix I contains the site team's work, Appendix II contains the panel's, Appendix III the inverter's work, and Appendix IV contains the financial team's work accomplished and recommendation.

Conclusion

From a financial perspective this project is feasible. The image below shows the overall proposed solar photovoltaic system for Rehoboth Christian School. All in all, the team proposes that Rehoboth Christian School install a 167 kW solar photovoltaic system in 2015, financed by a solar lease. This system would use 512 SunPower E20/327 panels placed on the fitness center, new high school, and band room roofs. This system would require eighteen Sunny Boy invertors. This system would offset approximately 47% of Rehoboth's annual energy consumption and would cost an estimated $573,162.



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Appendix I. Site Selection

Summary

Rehoboth Christian School is a large campus with a large need for energy. Different sites have different advantages and disadvantages. The first idea presented was to fold into the budget of the new high school a solar project. This led us to the new high school roof as a first installation and then branching off from there per percentage of energy the solar array should handle. The final proposal is a two phase installation of the new high school and band room and a second phase of the fitness center.

Introduction

Rehoboth Christian School has fields and buildings that could accommodate a solar system. From careful observation the class looked at the new high school, the high school parking lot, the sports and fitness center, and several other buildings new or old on campus. These were then compared to each other based on criteria with different importance. These locations were given to the panel and inverter team to analyze the area available to develop possible panel and inverter layouts.

Site Selection

After all locations were listed, the class talked to people who have been to Rehoboth who understand the culture there. Many of the things talked about in the decision matrix were aspects our class had issues putting numbers to. After a survey and several conversations with contractors and visitors of Rehoboth, weighted averages were assigned to different criteria in order to properly rank the locations. From this analysis, two locations were chosen for the initial installation and two more locations were provided as future options for expansion. Square footage of roof space was calculated and given to the panel and inverter team to calculate optimal pitch of the panels and approximate the percentage added to the system.

Conclusion

The new high school roof was chosen as the most ideal location along with the addition of the band room. A second phase would increase the total percentage of the system as compared with the usage of Rehoboth. This would be approximately 47%. The mounting for these systems include flat and metal roof fixtures. These fixtures do not penetrate the roof so the surface quality will be maintained. Weather in Rehoboth points to very favorable conditions for a solar installation.

Appendix I-A. Site Selection Process

Locations

New High School

The new high school is a preferred area for solar panel installations. The high school has not yet been built so the solar system can easily be implemented into the construction of the building.

Panel Layout

The new high school has a variety of areas suitable for solar panels. First, there are three large flat areas on the west side of the building, shown in Figure 1. These sections are made of Thermoplastic polyolefin (TPO) roofing. This material has a 20 year warranty and does not require much maintenance. Flat roofs are also easier to install onto and there are many different mounting options available. Another option for the new high school are the south facing slanted metal roofs, as shown in Figure 2. These roofs are at a 15 degree angle, which would help provide maximum power production from the solar panels. The metal roofs have the advantage of requiring almost no maintenance, however they can be more difficult and expensive to install onto. In addition to the previous advantages of these locations, the new high school is also very close to the utility tie-in.

Figure 1: Flat Roofs on New High School

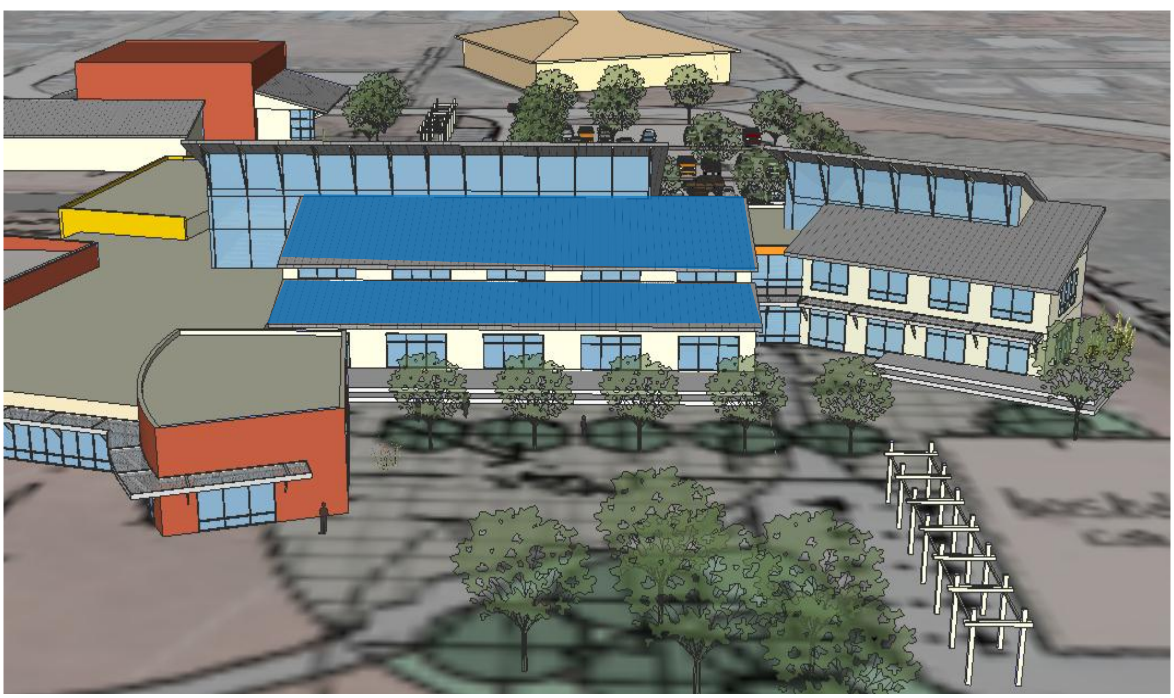

Figure 2: Slanted Roofs on New High School

Mounting

For the flat sections of the high school, ballast mounts are suggested. These mounts consist of plastic ballasts that the solar panels are attached to. The ballasts are filled with weight to hold them down. These are very easy to install and fairly inexpensive. For the metal sections, S-5 PV mounts are suggested. These mounts consist of simple clamps that can attached to metal roofing without penetrating the roof.

Concerns

The two different possible installation locations on the new high school both carry their own concerns. The flat roofs will include some obstructions on them, however since the final design of the building has not been completed these obstructions could be moved out of the way of the solar panels. The angled sections of the high school are in an excellent position for solar panels, but could negatively affect the aesthetics of the building.

Parking Lot

Parking lot solar canopies are a favorable option because the parking lots around Rehoboth provide plenty of space to install a large solar array. The main lot being looked into for solar panel installation is the large parking lot south of the fitness center. There is also another parking lot north of the middle school being looked into.

Panel Layout

The parking lot south of the fitness center provides a large area that could supply power for the entire community of Rehoboth. Parking canopies would provide shade for vehicles parked there and can come in a variety of different designs.

Mounting

The mounting methods used in parking canopies are preinstalled on each company's various canopy options. Typically, a racking system is used to mount the panels to the rooftop.

Concerns

The parking lot options brings up many different concerns. First of all, the parking lot is not close to the tie-in location and would require additional construction costs to install. This distance would also cause some line loss in delivering the power to the community. Finally, the parking lot brings up some cultural concerns. We are unsure how the people at Rehoboth might view the parking canopies. They could see them as an unfair luxury for the faculty and staff at the high school. Also, while parking canopies come in a variety of options, none of these options fit in aesthetically with Rehoboth.

Fields

One of the options was to use the large fields next to the high school. Using the area for the development of a solar PV array was attractive because the large amount of space available for use. These fields would provide more than enough space to capture the required energy via a solar PV system.

Panel Layout

With the fields, developing a panel layout would be simple and easy. Arrays could be setup in any number that would result in the most efficient production and the use of tracking systems could even be implemented to capture the maximum amount of sunlight. With a tracking system the team could eliminate the need for some panels and still get the required energy. Figure 3 shows the available land that could be used for the solar arrays.

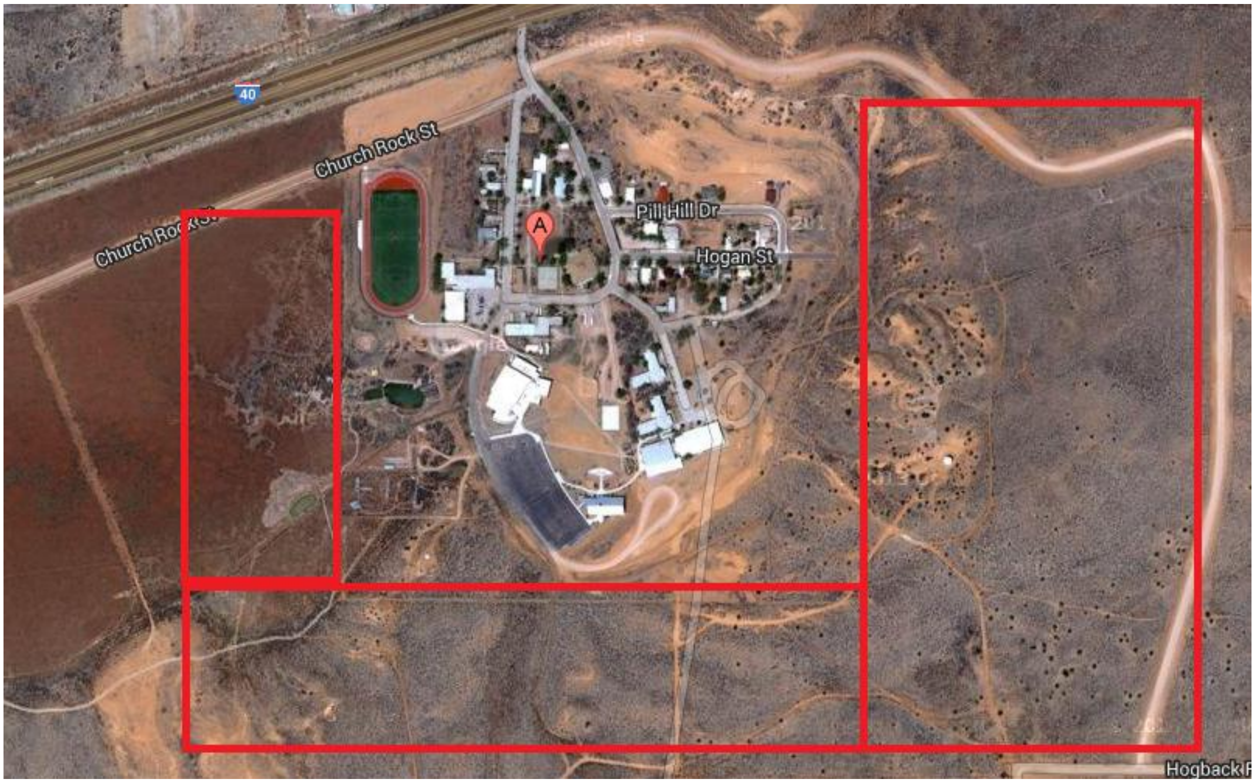

Figure 3: Field Locations

Mounting

The mounting for solar arrays in the field would be a little different than ones being mounted on a structure. These solar arrays would need to be to be secured to the ground in some way so they will not blow away in windy conditions. There are products out there meant for ground mounting on the market and they are rather simple to install. These mounting systems drive posts deep into the ground and the tops attach to a typical racking system for the panels.

Concerns

In the final decision for the location of the solar arrays, the team decided against the use of the fields. A few key issues arose with the use of the fields that convinced the team to peruse a different direction. One of the key issues that would have to be dealt with was the possibility if theft. Solar Panels are expensive and easy to steal. For this reason the team thought having the arrays on the ground might prevent some problems in that area. Another issue would be the tie-in distance to the grid. Having solar arrays in fields would mean long spans of wiring and more potential loss in efficiency due to traveling over these distances.

Walkways

One option considered mainly for future application was the idea of walkway canopies. These canopies would cover the main paths of the campus serving as both solar arrays and also convenient shading for pedestrians and students.

Panel Layout

The panel layout for these walkways would be rather simple. Canopies would be constructed with the arrays placed on top. Each section would be its own array and electric wiring would pass through the ground from the arrays.

Mounting

The walkway panels will be mounted on a system similar to that of the carport. Canopies will be constructed over top of the walkways on campus. These canopies would either be anchored by posts in the ground or they would be bolted to the sidewalks themselves.

Concerns

This addition to the solar project is a great idea but there are definitely some drawbacks. First off, the walkways are scattered over the campus and getting the energy collected from each one to the meters of the campus would require longer distance of wiring. A second concern would be the atheistic looks. The addition of solar panel walkways might look out of place in the current architecture. Lastly the fear of cultural acceptance was discussed. There are some who believe these walkways would appear to be more of a luxury to some rather than a sustainable source of energy.

Bus Depot

The planned location for the future bus depot is along Church Rock Street, just north of the current track and field. Construction of the bus depot is scheduled to happen following construction of the new high school.

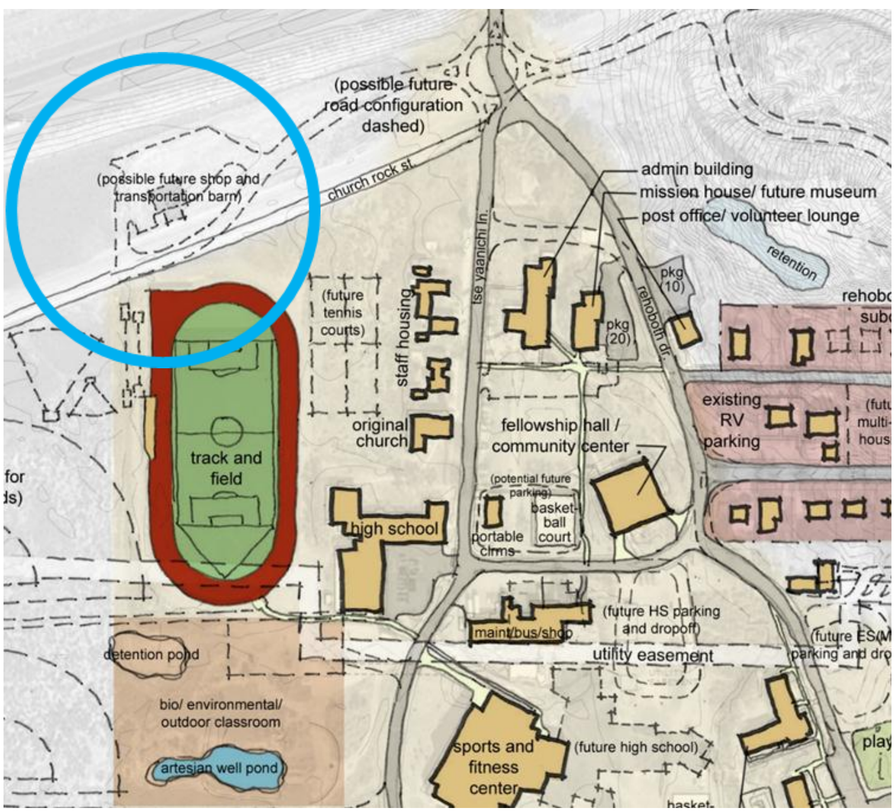

Figure 4: Location for future bus depot

Panel Layout

The panels will be mounted as one solid block. This way, the panels will cover as much area as possible to produce the largest possible amount of energy. The potential area available is approximately 5000 ft^2 for the bus port.

Mounting

The bus depot will consist of a roof structure with solar panels mounted on top of it. A racking system will be used to mount the solar panels onto the roof.

Concerns

The main concern for this location is if the construction of the bus depot actually goes through. A planned date for the bus depot construction is not set, so it may be some time until it is built. The bus depot location is most beneficial as an option for a later phase of solar panel installations.

Another concern is that the bus depot may not fit in with the culture of Rehoboth. The Navajo people may see the bus depot as more of a luxury instead of a necessity. It would look like a luxury because it provides shade to the buses, which is beneficial but not necessarily needed.

Sports and Fitness Center

The fitness center is a good option for solar panels because it is a relatively new building, being seven years old. There are two main areas of the rooftop that were looked at for installations of the solar panels. The first location faces south-southwest at 15 degrees from south. This rooftop is a great location because it faces close to directly south and has a slight tilt southward as well. The second location is the roof of the fitness center facing north-northeast 15 degrees from north. This roof also has an incline of 5 degrees.

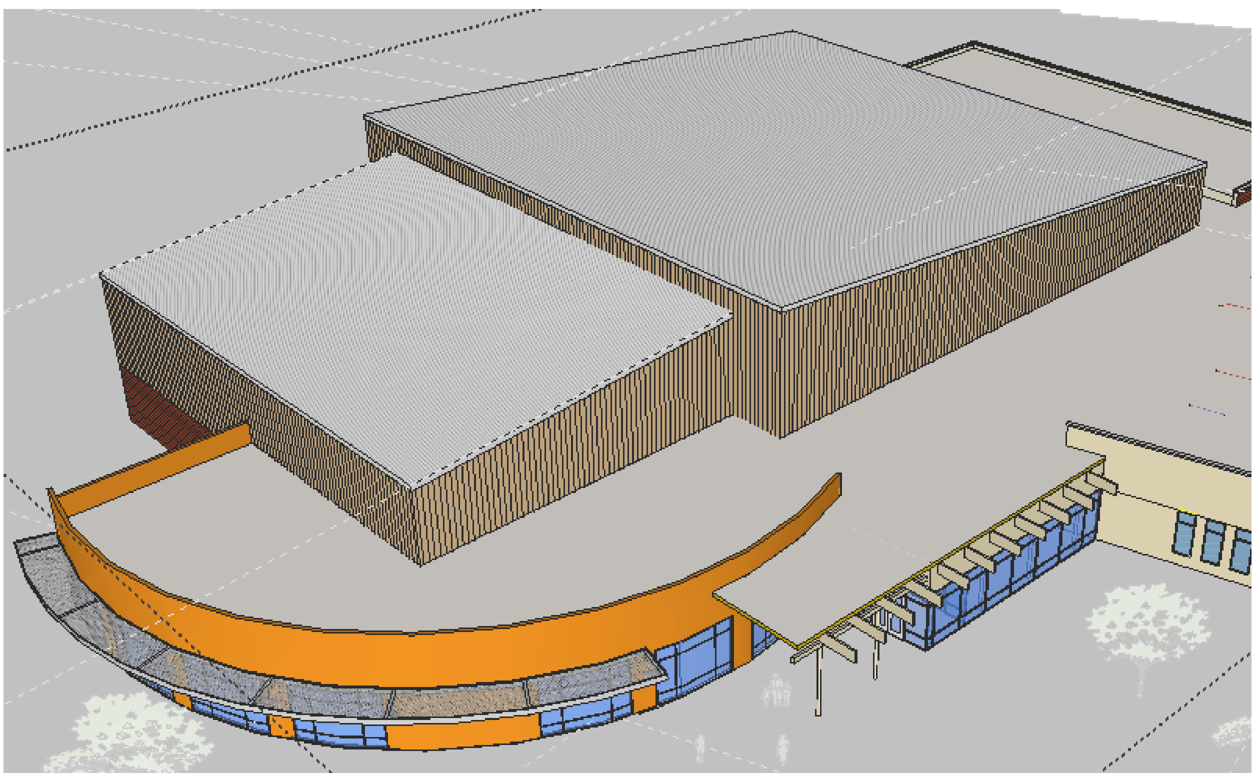

Figure 5: Sports and fitness center

Panel Layout

The rooftop of the sports and fitness center is metal and pitched at an angle of 5 degrees. Because of this, racking units will be used to mount the panels to the roof. The rooftop facing south-southwest has an area of approximately 6050 ft^2. Based on this area, 192 panels can be placed on the roof, fulfilling 17% of Rehoboth's energy consumption. The northern facing roof of the sports and fitness center has an area of approximately 14000 ft^2. Based on this area, it is estimated that 288 panels could be placed on this section of the sports and fitness center, which would account for 24% of Rehoboth's energy consumption.

Mounting

Both rooftop options for the sports and fitness center are metal roofing, so a racking system would be used for each option. The benefit of metal roofing is that minimal maintenance is required, and there are no obstructions reducing the available area for panels.

Concerns

One concern with the sports and fitness center is wind. The strongest and most frequent winds come from the southwest, so the south-southwest facing roof will be hit most directly by the majority of the wind. The wind gusts get up to 45 mph, and the selected panel is rated for up to 120 mph winds, so wind should not be a problem as long as the mounting system is strong enough.

Other Buildings

The other buildings that were considered are the elementary school, middle school, and dormitories. All three of these buildings have south facing roofs, making them viable options for a solar panel installation.

Figure 6: Dormitory on top and middle and elementary school on bottom

Panel Layout

The pitch of the dormitory roof is approximately 30 degrees. The dormitory roof does not have a large surface area, and therefore was not further looked into as an option for solar panels. The middle school roofs, however, do have a large amount of surface area. The area for the roof shown in the bottom left of Figure 6 is approximately 6500 ft^2, while the area for the roof in the bottom right is approximately 9900 ft^2. These roofs would account for 21% and 30% of Rehoboth's energy consumption. The panels will be placed side by side along the roof horizontally. The panels will be placed vertically, so the short side of each panel will line up horizontally across the roof.

Mounting

The roofing style of the middle school is not for sure known, but it appears that a portion is shingled and a portion is metal roofing. Racks can be used for the metal roofing to mount the panels onto, just like the mounting system of the sports and fitness center. For the portion that is shingle roofing, a racking system can still be used, but this causes more issues with roof replacement and maintenance.

Concerns

The main concern with the middle school is not knowing the allowable load capacity for the roofs. The roofs cover a large surface area, so there is great potential for many solar panels, but the allowable load capacity is uncertain.

Decision Matrix and Criteria

Decision Criteria

Part of the decision making process involved an initial survey sent out to contacts in order to get a general idea of what locations were preferred based on various decision criteria. Eight different decision criteria were selected to compare the various location possibilities. The decision criteria are:

- Aesthetics – How it fits in with the Rehoboth community
- Placement – Availability of structure versus need to build a new structure
- Security – Chance of damage/robbery of the panels
- Cost – Cost of site development
- Ease of Construction – How easy to build mounts and install panels in the location
- Tie-In Distance – Distance of location to electrical consumption/grid
- Total Area – Area available for panels to be installed on
- Cleanliness – How much cleaning would be required based on dust collection

The survey asked questions based on each of these decision criteria in order to rank the location options for each individual criteria. Another question asked to rank these in order of importance, so that the team could weigh the value of each decision criteria for what characteristics should be valued higher than others. From the survey and getting input from various contacts, the total area and tie-in distance were weighted highest of the various criteria. The area is important because the project will require several hundred panels to be installed. The tie-in distance is important because if this distance is too large, efficiency is reduced due to losses in the transportation of electricity through the lines.

Decision Matrix

Following the survey response, the team developed a decision matrix. The decision matrix includes six locations, and ranks them according to the decision criteria and the results from the survey. The decision matrix is shown below in Figure 7.

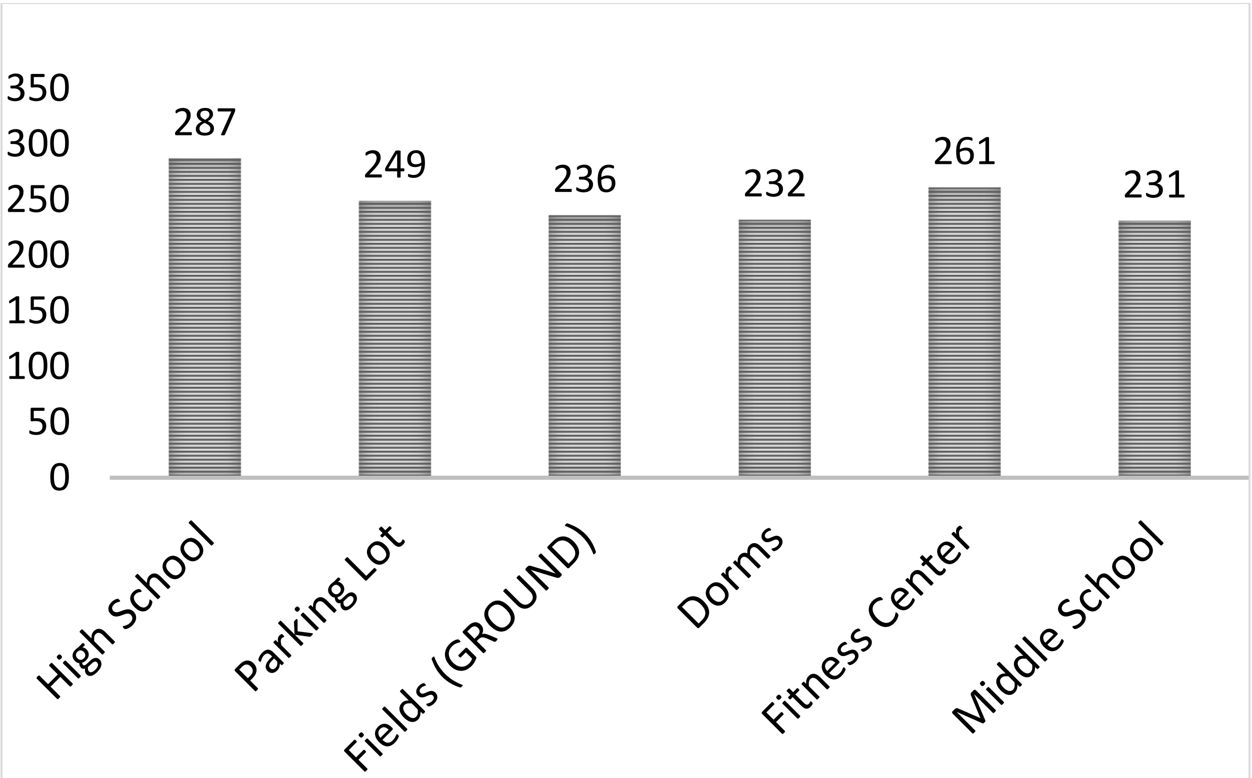

Figure 7: Decision matrix of potential locations for the solar panels

As seen in the figure above, the top two locations are the fitness center and the future high school. Both of these buildings are centrally located and will use the majority of the electricity that the solar panels produce. The tie-in distance for them is very small, and the rooftops provide a large area for panel installation. These two locations are the best options to be used as the primary installation.

Mounting Options

Plastic Ballasts

Many buildings around Rehoboth include flat roofs with a Thermoplastic polyolefin coating. These roofs are on areas like the flat portions on the new high school and have a higher durability compared to other roofing materials. For these the best option for mounting solar panels are plastic ballasts. These ballasts are held onto the roof by weights placed into the ballasts. Solar panels are then mounted on top of the ballasts. This option was favorable because it is easy to install and also does not require modifying the existing roof. The ballasts are also reasonably priced at around $30 per ballast.

Photovoltaic Roof Clamps

For metal roofs, such as those on the fitness center and part of the new high school, various attachment options were investigated. Most of these options were ruled out because they required piercing into the roof. This caused concern because of the possibility of leaking and other problems. Because of this, S-5-

PV solar attachment kits are the best option. These kits include clamps that securely hold onto the metal roof without penetrating the roof. Pricing for these clamps can be seen below in Table 1.

Table 1: S-5 PV Kit Prices

Quantity	2+ Cases	1 Case	2+ Boxes	Full Box
MSRP per/ea (US $)	$4.72	$4.97	$5.23	$5.50

Quantity	2+ Cases	1 Case	2+ Boxes	Full Box
MSRP per/ea (US $)	$5.52	$5.78	$5.78	$6.05

Note: One case includes 300 units, one box includes 75

Installation and Mounting Costs

For the initial installations, the cost for the ballasts and additional materials is approximated to be around $0.12/Watt. This value includes the cinderblocks, plastic molding, and racking setup for each individual panel on the flat high school roof and the band room. Installation costs for these mounting systems are approximated to be $1.68/Watt.

Appendix I-B. Environmental Concerns

Wind

Gusting winds can rip up solar panels if improperly secured. The ballasts are rated for 90 mile-per-hour winds, and the strongest gusting winds in Rehoboth, New Mexico are 45 mile-per-hour. Figure 8 shows the wind rose for Gallup, New Mexico. It can be seen that most often there is wind from the South West at 4 to 8 meters per second. Figure 9 shows the winds gusts for Gallup, New Mexico. This is where the max wind of 45 mile-per-hour is found. The chance of wind tearing the panels off of the roof is very small.

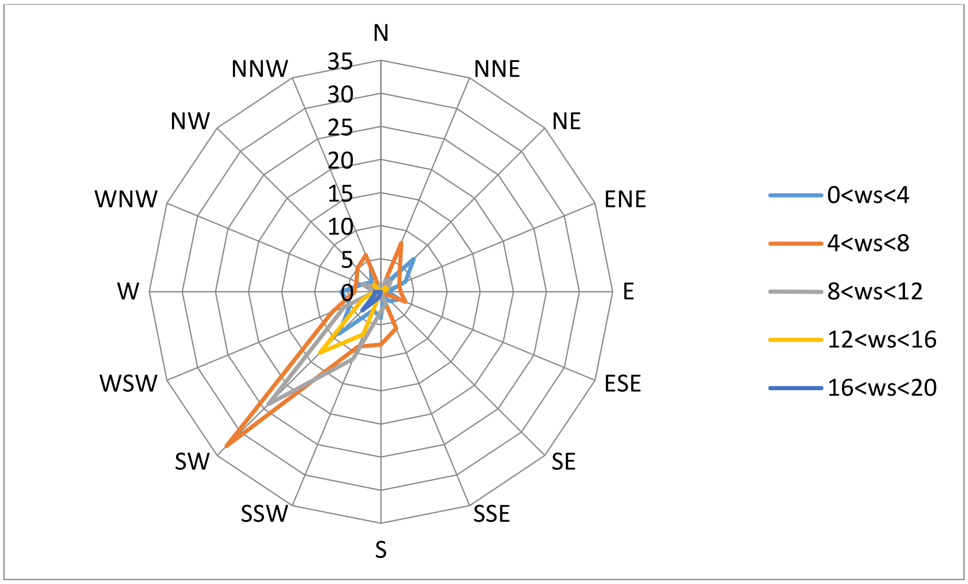

Figure 8: Wind Rose for Gallup, New Mexico in 2011

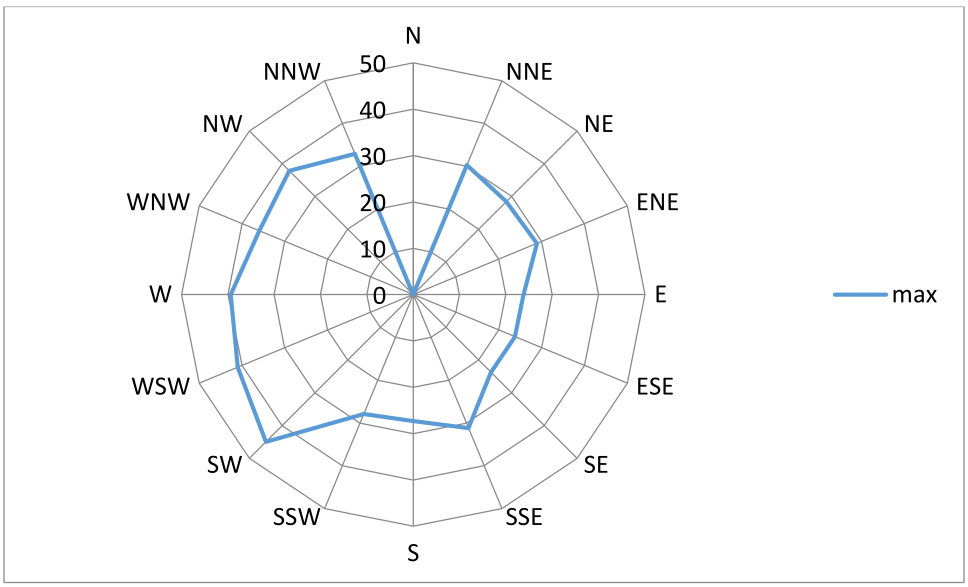

Figure 9: Wind rose for Gallup New Mexico showing max wind gusts in 2011

Dust

Dust is a problem in a desert plateau like Rehoboth is in. It can act like an abrasive against the glass of the panels, but the degradations are very small in comparison to if there was no dust blowing[1].

Precipitation

There is very little rainfall and snowfall in Rehoboth. Any snowfall does not accumulate because of the heat of the day. Figure 10 shows average rainfall and snowfall for Rehoboth.

[1] http://phys.org/news/2013-07-solar-panels-worth.html

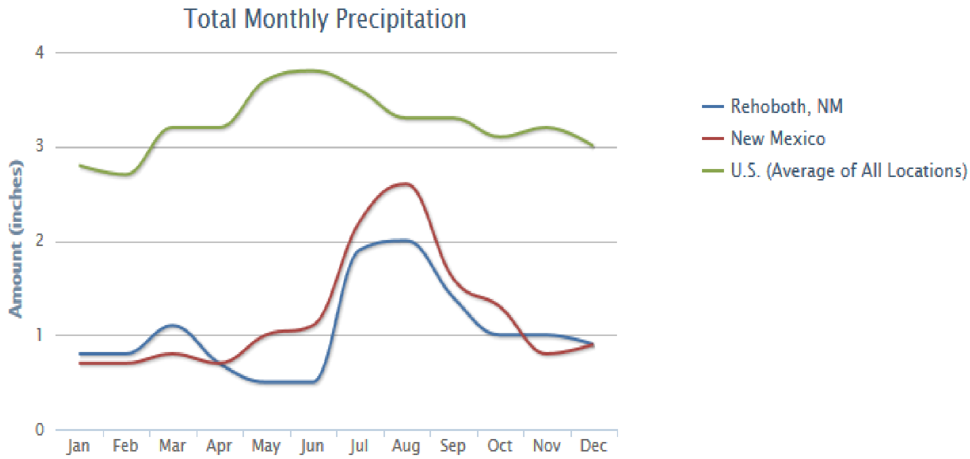

Figure 10: Precipitation for Rehoboth, New Mexico

Temperature

The panels perform the best under chilly conditions, but of course summer has the most direct sunlight. All electronics are rated for the temperatures in Figure 11.

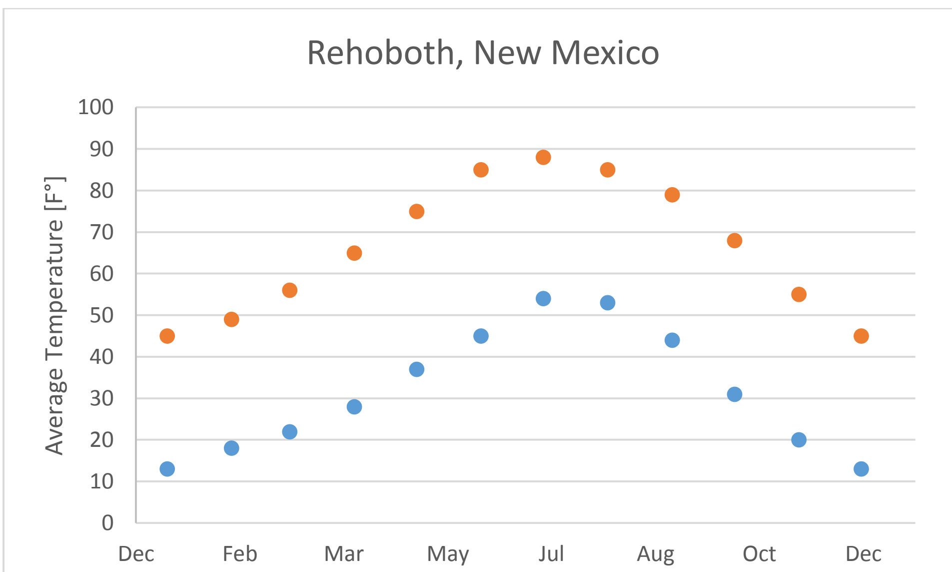

Figure 11: Average High and Low Temperature for Rehoboth, New Mexico

Appendix II. Panel Selection

Summary

The biggest challenge of the panel selection process was to determine which panels to use since there are many different types, each with distinctive features. The panel team determined that monocrystalline panels, specifically E20/327 by SunPower would yield the optimal result given the available site and inverter options. After analyzing optimal panel angles and spacing, the team designed a few layout options using Google Sketchup. Overall, the team's proposed design would generate approximately 47% of the annual power usage from calculations with the new high school building in place. This was calculated to minimize system cost and other possible issues including wiring and metering, while providing optimal inverter options. Different phases are suggested by the team to suggest different options to the decision makers depending on Rehoboth school's needs.

Introduction

The panel team was delegated to determine which solar panel, tracking system, and panel layout would be used for the arrays. Comprehensive research was completed on each of these systems in order to determine which would be optimal for the Rehoboth community. The major requirement of the project was to yield approximately 50% of annual power consumption with the new high school expansion included.

Procedures

Panel Selection

The team analyzed several different panels from different manufacturers. A decision matrix was organized using the following categories: Efficiency, Cost, Weight, Panel Area, Capacity, Company Stability, Aesthetics, and Warranty. From the decision matrix, the SunPower E18/305 was selected at first. However, the team was told by a solar panel supplier in California that SunPower does not manufacture these panels anymore. Hence the team has chosen to use E20/327 which was recommended by the supplier, and also was the second best option based on the decision matrix.

Tracking System

Panels can be mounted on fixed frames or moving frames. The team selected fixed frames to mount the panels, based on research and existing schools similar to Rehoboth.

Panel Layout

The site team provided the best locations for solar panels, and the panel team then analyzed how many panels could fit in each location and how much power each could generate.

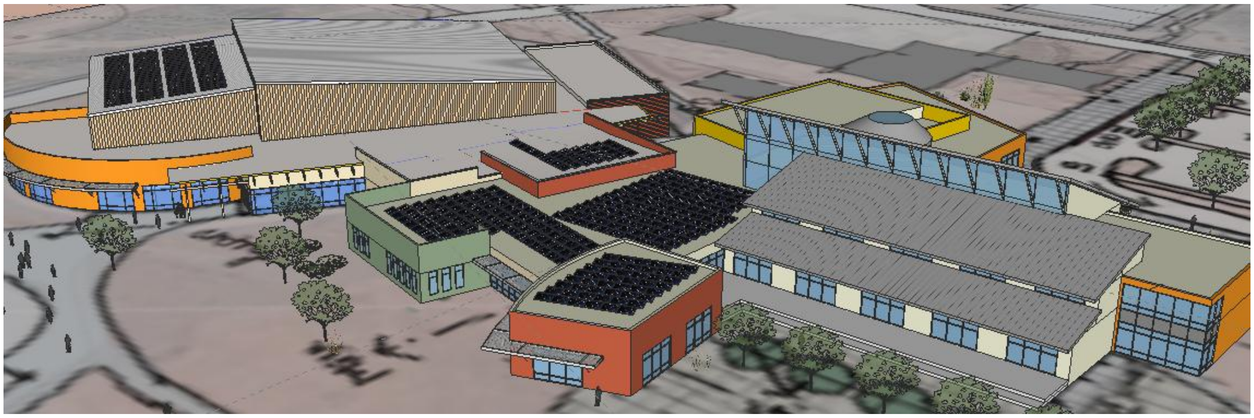

Figure 12: Final Panel Layout

The primary goal of approximately 50% will be reached by utilizing the locations shown in the figure above. Actual annual generation from these locations is calculated to be approximately 45% with the new high school building in operation increasing the annual usage.

Power Calculation

SunnyDesign software was used mainly to calculate the power generation. Locations used for panel installation include the South facing roof of the current high school building, band room roof, flat roof of the new high school, and the small strip of the flat roof of the new high school building. Total power generation rate was calculated to be 167.4 kW by using 512 panels.

Data & Calculations

The annual energy yield was found using the SunnyDesign SMA software. Using this software, the panels were arranged according to the respective areas and inclines found in Table 3 of the Appendix. This total calculation yields an annual energy production of 291.5 MWh, or 47.5%. In addition to this, future projects may be added to the north roof of the fitness center, the middle school roofs, or another roof on the new high school. However these sites each have aspects that make them less appealing which is discussed in the future plan section and more information is needed in order to justify adding additional weight on the middle school roof.

Conclusion

Based on the team's calculations and research, the team suggests to use 512 SunPower E20/327 panels to obtain approximately 47% of annual power usage with the new high school building in operation which will produce 291.5MWh annually. The installation sites include the high school building roofs, the flat roof of the band room, and the new high school building flat roof. Price of each panel is estimated to be $412. The component cost estimate for the panels not including the installation cost was found to be approximately $211,000, with cost per watt of $1.26/W. The team suggests to not use a tracking system.

Appendix II-A. Procedures

Panel Selection

There are many types of solar panels with different pros and cons. The team considered three distinct types of panels; monocrystalline, polycrystalline, and thin-film panels. Each of these panel types offer different advantages for different situations. Crystalline panels offer better efficiencies than other types such as Thin-Film or BIPV (Building Integrated Photovoltaics). The quality of these crystalline panels are determined by the type of silicon used for the panel.

Monocrystalline

Monocrystalline panels are the best quality panels with the highest efficiency among all other kinds of panels. The only disadvantages of monocrystallines is the extra 10 – 20% cost the buyer has to pay for the component, and the fact that if one panel is shaded or covered by other obstacles the entire circuit can be broken down, not producing any electricity from that string. However, the team has decided that the advantages of these panels overtake the extra cost.

Polycrystalline

Polycrystalline panels, on the other hand, have a lower cost but also a lower efficiency.

Thin-Film

Another commonly used type of solar panel is the thin-film. These are applicable for situations where extensive space is available because mass production of these panels is much easier than crystalline panels and at a much lower cost. But efficiencies for this panel are much lower than the types of panels. Another merit of thin-films is that these panels are flexible thus making them more aesthetically pleasing than hard framed crystalline panels.

Decision

For the Rehoboth community, the major requirements/limitations that the team faced were specific annual power yield, and the fact that available installation space was limited to rooftops of buildings in order to minimize additional structural costs and wiring costs. The panel team put together a decision matrix in order to determine the best option. The team selected the SunPower E20 327W panels due to the following reasons.

Figure 13: SunPower E20/327 Model

1. The average efficiency of monocrystalline lies between 15-20% which is much higher than Thin-Film (7-13%), and approximately 3-7% higher than polycrystalline panels
2. The average cost is approximately 5-15% higher than polycrystalline panels but degrades only 0.25% a year which is roughly 4 times less than most other panels

3. The amount of available space is limited, which led the team to select panels with higher efficiency in order to meet the required annual power generation
4. The installation process for these panels can be done without any technical challenges, and installing crystalline panels is commonly done in the industry and at many other schools
5. The performance of monocrystalline panels does not drop as much as polycrystalline panels or thin-film when exposed to high temperatures
   SunPower is a very reliable company and has been in the industry for 30+ years

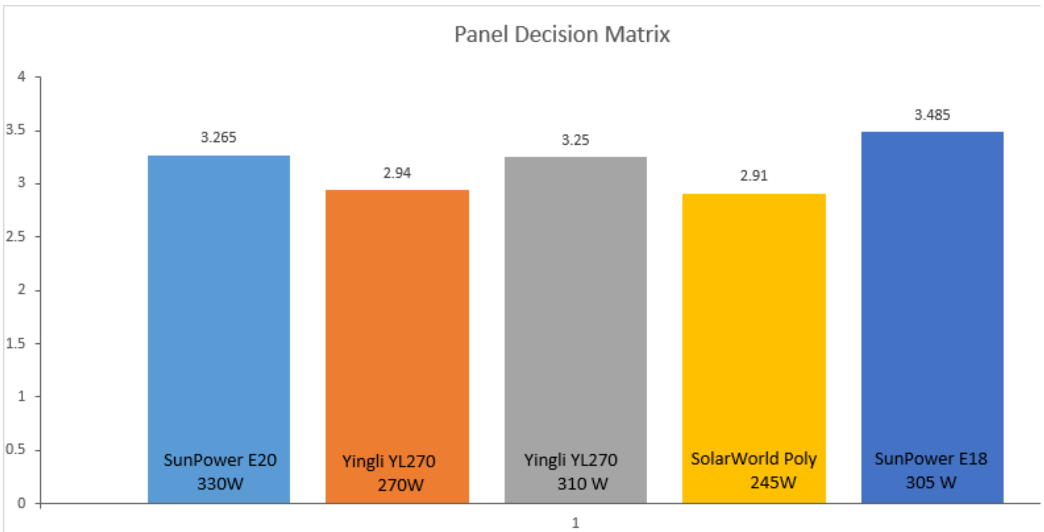

Figure 14: Decision Matrix Showed Inconclusive Result

Table 2: Decision Matrix Table

Categories	Weight (of category)	SunPower E20-327	YL270C-30b	Yingli YL310P-35b	SW 245 poly (solarworld)	SunPower E18 / 305 SOLAR PANEL
Efficiency (%)	0.18	3.5	3	2	2	3
Cost ($)	0.23	0.5	2	5	3	2.5
Weight (kg)	0.09	3	3	1	2	3
Size/ Area (m^2)	0.05	3	3	2	3	3
Capacity (W)	0.15	4	2	3	1	3
Company Stability	0.08	5	3	3	5	5
Aesthetics (unitless)	0.1	5	5	5	5	5
Warranty (years)	0.12	5	4	3	4	5
TOTAL:	1	3.265	2.94	3.25	2.91	3.485
		MONOCrystaline		POLYCrystaline		

Efficiency

Efficiency was weighted as the second most important factor because it plays a major role in balancing the cost, required area, and power generation.

Cost

Cost was the most important factor in the decision making process. It was very difficult to obtain prices for the panels. Companies hold this information very close, and they also generally quote entire systems, not individual panel prices. Extensive research was done to find these exact panels from other vendors.

Weight

It was important to know the weight of each panel to ensure the system as a whole could be sustained by the respective buildings.

Panel Area

Each site had a certain amount of area available. The panel dimensions were used to calculate how many panels could be fit onto each roof.

Capacity

Capacity was the amount of power each panel was capable of generating. This was also used to find the amount of power each site could generate. It was ranked as the third most important factor.

Company Stability

The solar panel industry is notorious for companies coming and going. It is important to purchase panels from a stable company who will be in the market long term. Warranties are voided if a company goes out of business, and panel replacements can be hard to find.

Aesthetics

Initially, aesthetics were considered as an important factor per Jeff Banaszak's request. However, since the panels installed at the selected locations would be hidden from people's point of view from the ground, the same score was inputted for all of the selections.

Warranty

Companies guarantee their products for a specified number of years. During this time, if panels malfunction, the company will replace them at no cost to the school.

Tracking System

The moving frame tracks the sun as it moves across the sky in order to obtain as much direct sunlight as possible. The major drawbacks of this tracking system is how expensive the mounting is, how heavy the individual units become, and how much more spacing is required between panels.

Figure 15: Tracking Panels

Because of these characteristics a tracking system is best suited in an open field. The tracking of the sun is more effective in less sunny regions, and New Mexico is a particularly sunny area so the benefits of tracking over fixed frames is minimized. Panels that do not move can use far lighter mountings, and can be placed on the roof of a building. Since the top sites for Rehoboth's campus were on top of buildings and the fact that tracking systems are so expensive, the fixed mounting frames were selected for all panels.

Appendix II-B. Data & Calculations

Panel Layout

Using the site team's recommendations with regard to integrating a solar system into the future high school addition, as well as into the existing fitness center, the panel team was tasked with determining the most effective way in which panels could be incorporated into the new high school design. This determination focused on an evaluation of different areas of the high school, upon which solar panels could be placed. Because solar panels seek to harness the sun's energy, building areas that are exposed to the largest amount of sunlight for the longest period of time provide the best opportunity for capturing optimum amounts of the rays of the sun. Keeping these facts in mind, the logical optimal location for solar panel placement are building rooftops due to the fact that they provide the largest amount of area and are exposed to the largest amount of sunlight for the longest period of time. The next step in the panel implementation process was to decide between different roof areas. This was done using several criteria including the following: roof area available, roof obstacles, roof orientation, roof structural integrity, and building aesthetics.

Roof Area

One of the biggest considerations with regard to selecting panel mounting locations is that of roof area. This is due to the fact that in the design of solar arrays, area is fundamental. If more area is available to place solar panels, there is more opportunity for increased energy generation capacity. In other words, energy generation from solar panels is a direct function of solar panel area. Another consideration is roof obstacles. If obstacles such as building corners and overhangs, roof vents, or roof mounted HVAC equipment cause shading on roof-mounted solar arrays, any panel and string (group of solar panels wired together) that experiences this shading will be prohibited from generating energy. In addition to roof obstacles, roof orientation is also important. The team chose building roofs that were either flat in orientation, or that had south-facing orientations.

Roof Stability

This choice was made in order to obtain maximum sunlight exposure throughout the course of a day and throughout the course of a year, as the sun moves across the sky from east to west. Furthermore, roof structural integrity was an extremely important design consideration. In order for a roof to be a good option for implementing a solar array, it must be strong enough to hold the excess weight provided by the solar panels as well as the mounting equipment. For existing roofs such as the fitness center and band room, this criteria could be one of the biggest issues with regard to installing panels. For future buildings such as the high school addition, this would not be as big of an issue due to the fact that the high school can be designed to bear the excess loads that solar panels and associated mounting equipment would create. A final important solar layout design consideration was that of building aesthetics. In order for a roof to be a good option for the project, building aesthetics from both a local culture standpoint as well as from the architect's standpoint (AMDG Architects), must be acceptable.

Location Decision

Using the criteria found in the decision matrix, the fitness center south roof and the flat roof of the new high school were deemed the highest priority. Following these two locations, additional locations were analyzed to produce additional power to exceed the 50% goal of total Rehoboth consumption. When analyzing these future panel sites, it becomes clear that the north face of the fitness center is the first priority. This is primarily from the large space available and the close proximity to the grid tie-in. The other options of the middle school and sloped roof of the new high school also fulfill this criteria, but are less aesthetically pleasing and also unknown regarding the allowable loads.

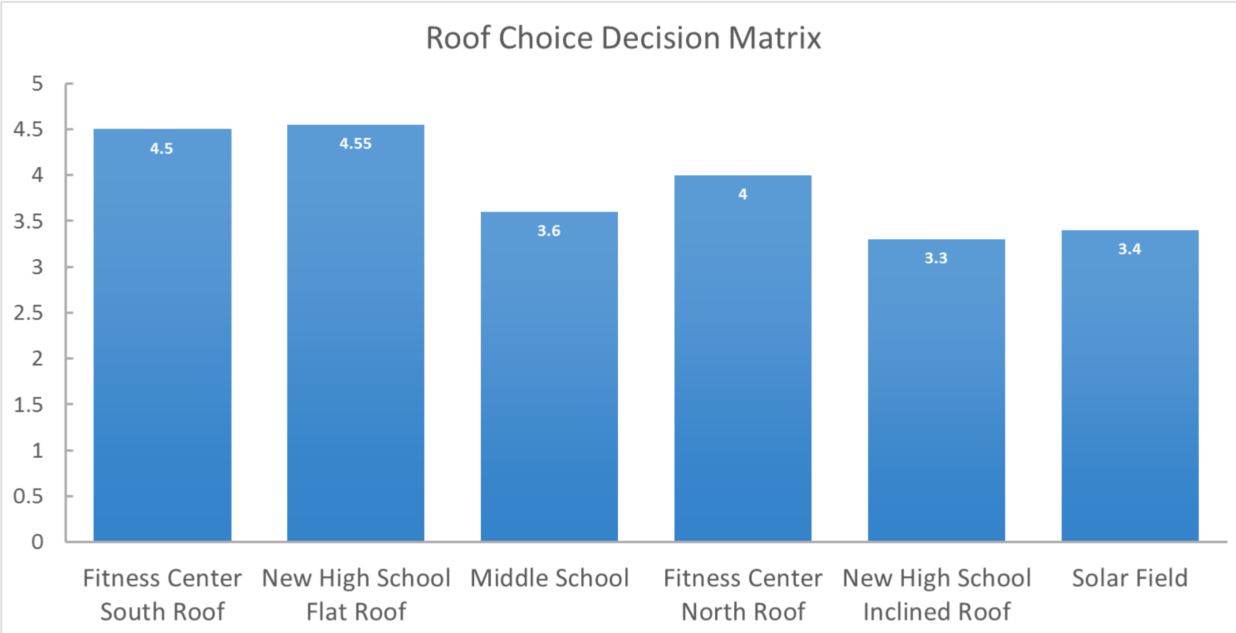

Figure 16: Roof panel layout selection decision matrix

Panel Orientation

After selecting optimal roof areas for solar panel placement, several other factors were taken into account when determining how the panels should be laid out on the various roof areas. First, for sloped roof panel layouts, such as the fitness center, panels were laid out in pairs in long rows. It was then determined that two foot wide paths should be left between these rows to allow for accessibility to panels should any maintenance or troubleshooting need to be performed. Also for sloped roof layouts, it was determined that a minimum of six feet should be left around all roof perimeters in order to allow for solar system serviceability, should the need arise. Although no roof perimeter regulations were found that were specific to the state of New Mexico, this value was determined based on research of other state's regulations and also in accordance with government regulations.

In addition to panel layout considerations described above, additional research and calculations were performed in order to obtain more detailed panel orientation information, especially with respect to mounting those panels upon the prescribed roofs. For mounting, the team calculated that panel angle of 25 to 30 degrees would yield the most power from the system. This was done using a sun angle calculator found online (See Figure II-2), and was verified according to Consolidated Solar Technologies. However, since the industry standards for plastic mounting kits typically lie between 10 and 15 degrees, and purchasing custom designed mounting kits would drastically increase upfront cost, it was determined that 15 degrees would be the optimum mounting angle for flat roofs. Further analysis of this mounting angle was performed using Sunny Design, which revealed that using a 15 degree panel orientation would only reduce annual power generation by 1%, in comparison to 25 degrees. Hence, the team decided to use standard mounting kits for the flat roofs of 15 degrees to minimize the overall installation cost.

Using the panel layout information described above, panel layout configurations were performed. These panel configurations were implemented in a Google Sketchup file of the existing fitness center and the future high school expansion that was provided to the team by the architect, Peter Baldwin (AMDG Architects). Note that for the sloped roofs, panels were placed in a "portrait" orientation, while for the flat roofs, panels were placed in a "landscape" orientation. This was done based on research of panel layouts used in existing solar arrays, as well as in accordance with the mounting systems chosen, and also according to the recommendations of Chuck Holwerda, electrical technician at Calvin College.

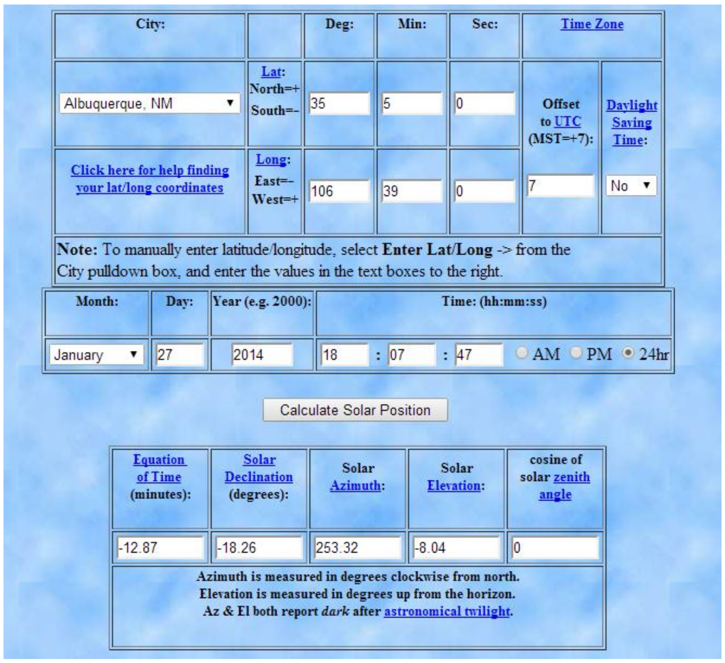

Figure 17: NOAA ESRL Solar Position Calculator

Panel Spacing

Furthermore, analysis focused on determining the optimal distance between panels in order to achieve the highest efficiency from the panels. This is only a concern for the panels on the flat roofs due to the fact that their orientations could potentially cause shading on other panels. During the winter months, the minimum high point of the sun is 32 degrees from the ground, compared to a maximum of 78 degrees during the summer months. As previously stated, the panels on the flat roofs should be placed horizontally and at an angle of 15 degrees. In addition, as previously mentioned, the panels on the flat roofs should be placed in a “landscape” orientation. In a “landscape” orientation, the panels have a width of approximately 3.5 feet, as shown by the panel dimensions figure[2] below. Based on these values in addition to the sun angles, it was determined that the panels must be spaced a minimum of 1.5 feet apart in order for panels to not be shaded by other panels. Additional calculations were performed for a 10 degree ballast in case the 10 degree ballasts prove to be a better option. Based on a 10 degree angle, the panels would need to be spaced 1 foot apart in order to prevent any shading from panels onto others. The 10 degree incline would allow for 1 additional row of panels to be installed on the future high school roof,

[2] http://www.ffsolar.com/products/pdf/modules_sunpower_spr-327-333-WHT_en.pdf

but on a cost per kW basis, due to the increased efficiency with a 15 degree incline, the 15 degree ballasts are the better option.

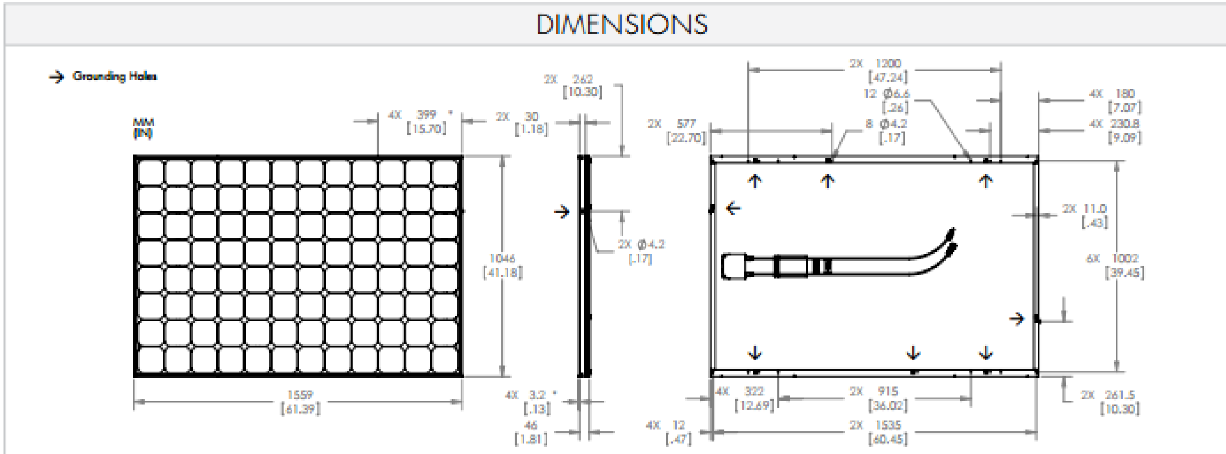

Figure 18: SunPower E20/327 Panel Dimensions

In addition to the above distance calculations, further calculations were performed to determine how close to parapet walls panels could be placed on the flat roofs. This calculation mainly applies to the panels that are placed on the high school addition. Again, this calculation was based on the sun angles previously mentioned. For the highest parapet wall in front of panel mount locations on flat roofs previously described, it was determined that the front edges of panels should be placed at 10 feet from those walls. This value was carried over for all locations where parapet walls were present, even if the parapet wall was shorter than the highest parapet wall upon which the calculation was based.

Power Calculations

The calculations shown on below table are attained by using SunnyDesign software to illustrate how much power each site can generate with specified setup for panel angles and direction. The team worked together with the inverter team to configure the best combination of panels and strings to determine required inverter type and number of inverters for each site. Estimated cost per watt of $1.26/W is found by talking to a representative of SunPower solar panels in California for panels, Herca Solar. With this information, the team was able to estimate the cost per panel and the total panel cost ($412.0 per panel, 512 panels, $211,000 total).

Table 3 shows the strings and panels necessary to meet the goal stated above. In order for this to be properly paired with a three phase system, the band room system, which runs on two inverters, must be tied into the high school system in order to form a proper inverter system to tie into the grid.

Table 3. Power Calculation Table

Building	Orientation	Incline (˚)	Total Number of Panels	Annual Energy (MWh)	% of Energy
Band Room	S-SW 15˚	15	48	28.6	4.8%
Fitness Center	S-SW 15˚	5	192	108.3	18.3%
High School	S-SW 15˚	15	224	126.4	21.4%
High School	S-SE 5˚	15	48	28.2	4.8%
Fitness Center	N-NE 15˚	5	288	150.3	25.4%
High School	S 0˚	15	192	114.3	19.3%
Middle School	S-SE 10˚	13	224	132.2	22.3%
Middle School	S-SE 10˚	13	256	151.1	25.5%
TOTAL:	*N/A*	*N/A*	512	291.5	47.8%

These locations shown above may be seen in Figure 19, with the red locations representing optional future sites for a power production of over 50%.

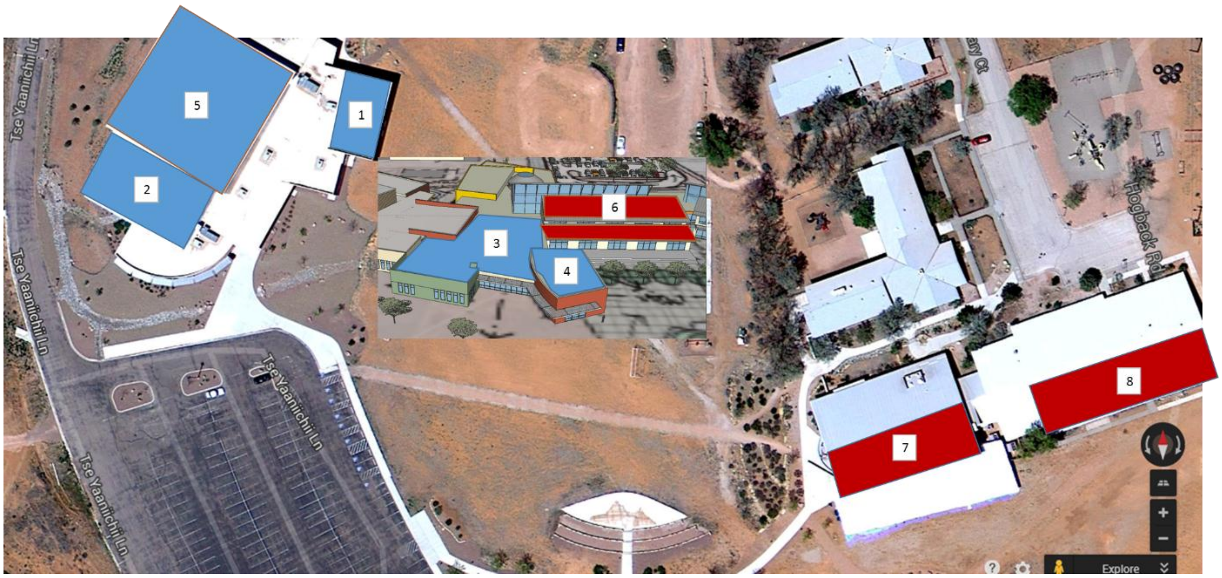

Figure 19: General Layout Locations Considered

More information is required in order to successfully implement these future options. This includes coordinating with a civil engineer on the designs of the future high school, the allowable loads of both the fitness center and the middle school roofs, and the aesthetics of each location. More detailed view of each building is shown in the figures below.

Figure 20: South Facing Roof of the Fitness Center

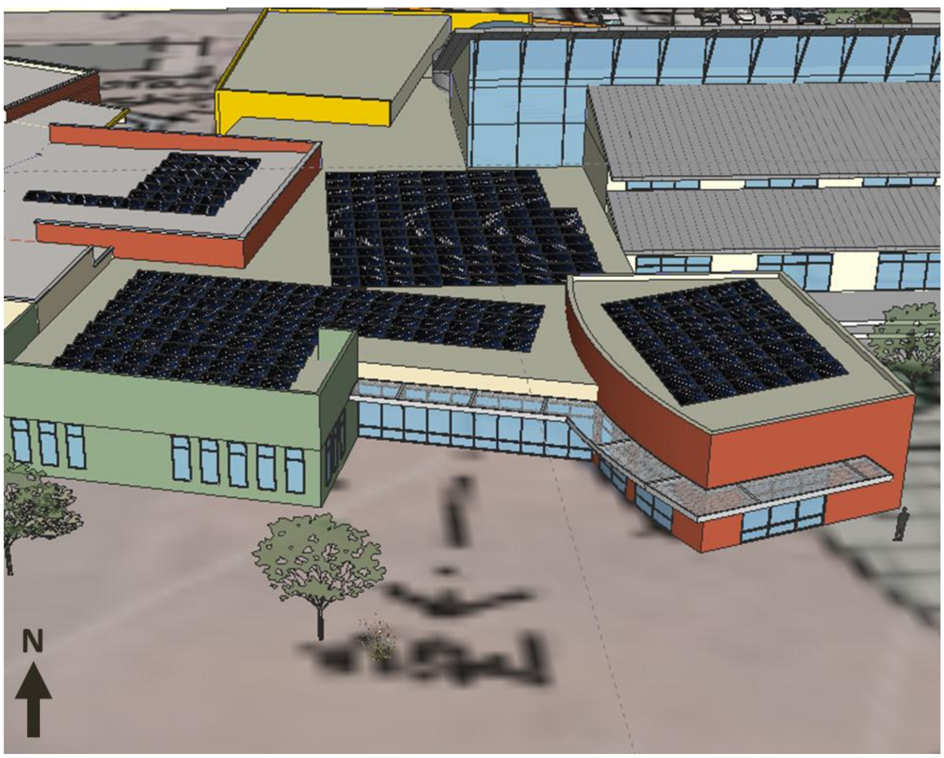

Figure 21: New High School/ Band Room

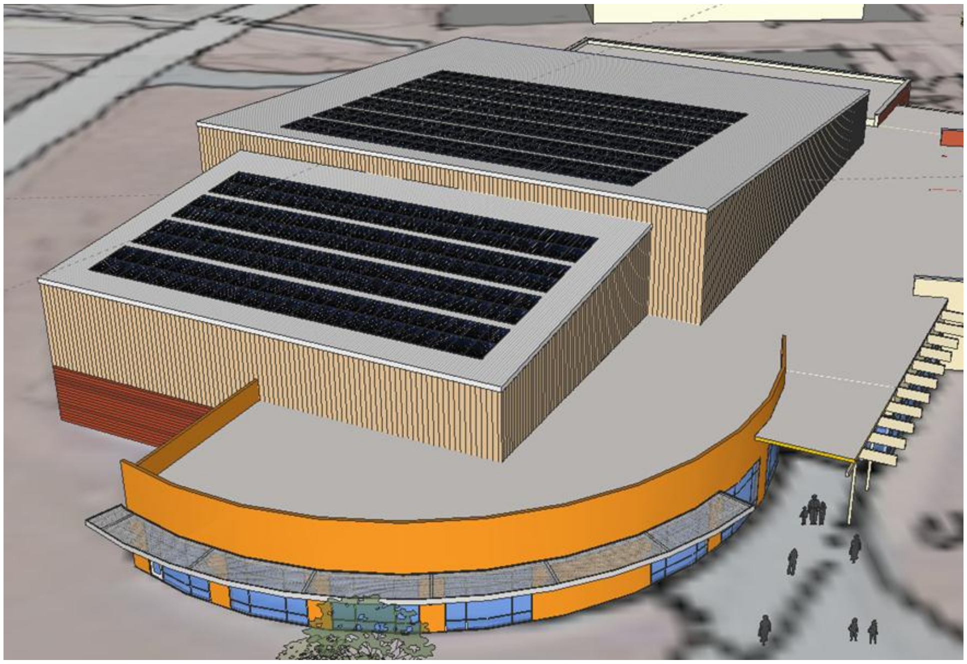

Figure 22: Fitness Center North Roof

Figure 23: New High School Slanted Roof

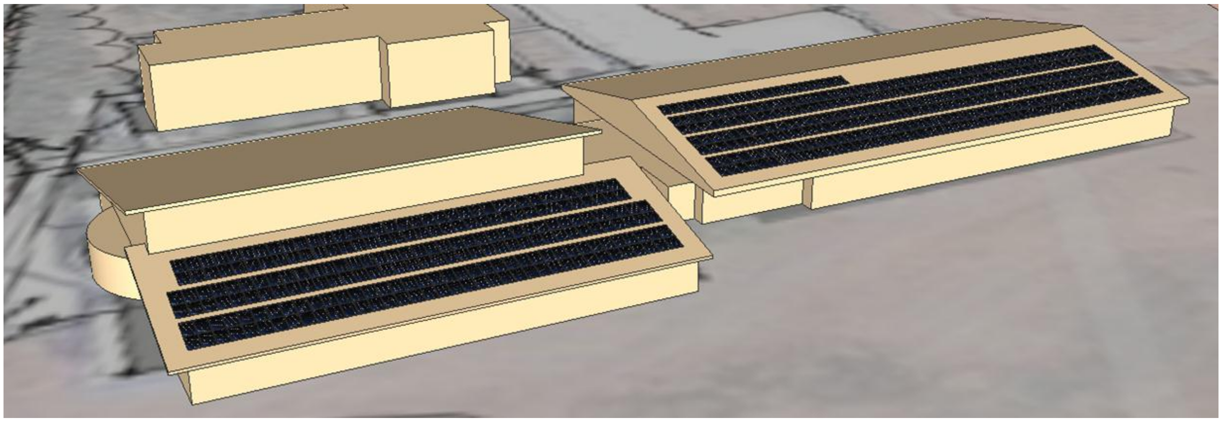

Figure 24: Middle School

Appendix III. Inverter Selection

Summary

Introduction

Inverters are a crucial part of the PV system. Without them the sun would not be able to generate useful power for building applications. An inverter takes the DC current that comes from the solar panels, and turns it into AC current which can be used to power buildings and potentially sent back to the grid. There are three primary types of inverters on the market today, micro-inverters, string inverters, and central inverters. With a central inverter, one inverter is used to handle a whole large commercial system; with string inverters, multiple inverters would be need to be tied together using a combiner before they are tied to the grid. Micro-inverter systems utilize one inverter per panel and the AC power of all these micro-inverters is combined and sent to the building or gird. No matter what type of inverter is chosen almost all utilities require that there is a disconnect switch between the system and the grid. A monitoring system workings in conjunction with the inverters. The monitoring system allows users to see how much power they are collecting, as well as other measurables such as how much power is being used and the amount of sunlight that the panels are receiving. For this project string inverters were chosen as they were the most affordable option, and they allowed the system to be tied into multiple buildings to alleviate to need to potentially expand a building electrical system's current rating.

Procedures

When looking at different companies that make inverters it is important to consider the stability of the company. Inverters are not cheap, and usually come with a 20-25 year warranty. If the inverter is purchased from a company that declares bankruptcy after the purchase, then the warranty on that inverter is useless. This means that if the inverter goes down for any reason it will be very expensive to fix or replace it. Another reason for finding a stable company that is not going to go anywhere is that the company has probably been in the market long enough to know what makes a good inverter, and the quality of their products will most likely be better than a newer company.

Data & Calculations

One tool that has been helpful in analyzing data, and making an inverter choice is Sunny Design. Sunny Design is a software created by SMA Solar Technology. SMA Solar Technology produces many of the parts for solar systems outside of the panels themselves. Sunny Design takes a panel choice and inverter choice, and use direction, angles, and weather data to analyze the system and output an annual power estimate based among other things.

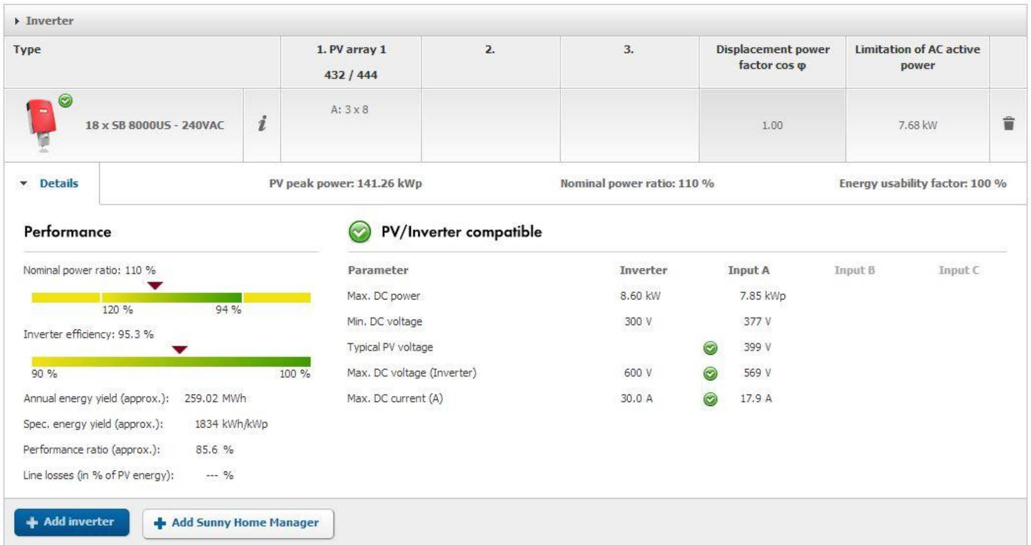

Figure 25: Example Output Screen from Sunny Design

Figure 26 shows an example of the output that comes from Sunny Design, and these outputs were used to make decisions on other equipment such as the combiner and disconnect switch. An iterative process was used to optimize the panels and the inverters to find the maximum annual power output.

Results

Based on the outputs from Sunny Design, as well as considerations of the sustainability of the company three different models of Sunny Boy Inverters have been chosen. The inverters are the Sunny Boy 5000 TL, the Sunny Boy 8000 TL, and the Sunny Boy 10000 TL. Three different inverters were chosen to optimize the performance of the converter based on the different arrays. Each array has a different number of panels that forms it. Having arrays with different panel numbers means that each array has a different power output. Each inverter model is rated for a different capacity, and this allowed the team to maximize the capacity of the inverter based on the different powers of the strings. Table 4 shows the three different inverter types with the number of inverters used and the cost of the inverters.

Table 4: Inverter Costs for 167 kW System

Sunny Boy 5000 TL (3):	$ 6,642
Sunny Boy 8000 TL (2):	$ 4,548
Sunny Boy 10000 TL (13):	$ 39,806
Deck Monitoring System:	$ 5,633
Tie-in components:	$ 4,226
Total:	**$ 60,855**

The total number of inverters is 18 for an inverter cost of $50,996.00. A solar monitoring system will also be necessary. The team has chosen Deck Monitoring Systems based on the reputation and previous experience with the company. The system also requires a combiner box to take the power of the different inverters and output one line to the grid. Also, Gallup Joint Utilities requires a disconnect switch to go between the solar system and the grid tie in. With all these cost considerations the total combined inverter system cost was $60,855.00.

Conclusion

In conclusion, 18 total inverter types were chosen for the proposed 167 kW system. 3 Sunny Boy 5000 TL inverters, 2 Sunny Boy 8000 TL inverters, and 13 Sunny Boy 10000 TL inverters were chosen for use. Combined with the Deck Monitoring system and other parts necessary for the implementation of the system, the total system cost is $60,855.00

Appendix III-A. Inverter Selection Process

Inverter Types

Micro-inverters

Micro-inverters are used for both residential and commercial applications. In this type of system each panel has its own micro-inverter with the outputs of the inverters tied to a central location. Having each panel have its own individual inverter has several benefits. One benefit is that this type of system works well where shade can be a factor. In an array if one panel is in the shade and not producing power then the whole array does not produce power. In a micro-inverter system shade only affects the one panel and does not shut down a whole array of panels. Another benefit to a micro-inverter system is that the production of each individual panel can be monitored. The monitoring system can look at the output of each individual inverter, which is great for troubleshooting the system. Any problem in the system can then be pinpointed to an individual panel with ease, as opposed to seeing that an array is down and trying to figure out from there which panel is the problem. Although micro-inverters seem like a good choice there is one downside to this type of system. This inverter type has the highest cost per watt. Figure 28 shows a comparison of the different types of converters and their costs. An example of a micro-inverter is shown in Figure 267.

Figure 26: Micro-Inverter Example

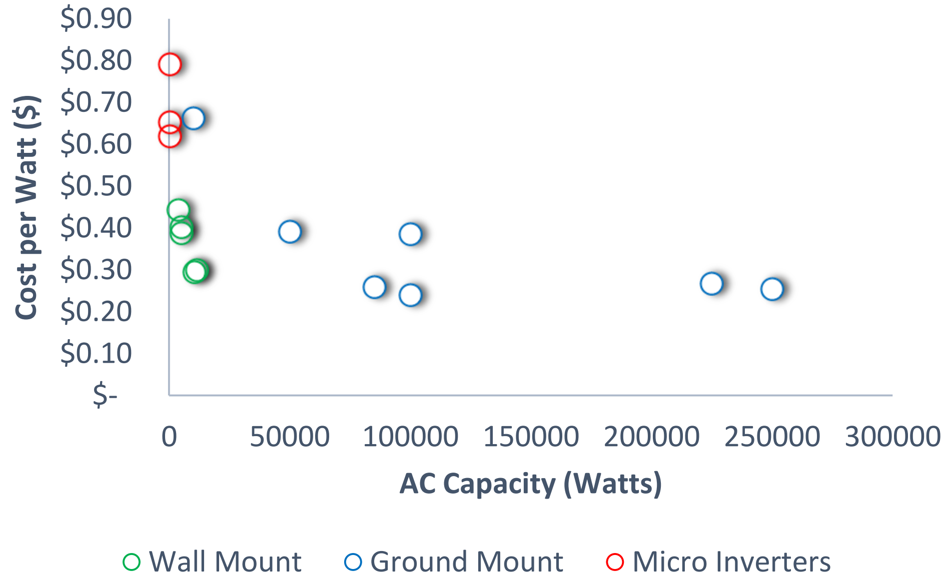

Figure 27: Inverter Type Cost Comparison

The cost per Watt of micro-inverters range from $0.60-0.80 per Watt, which is the highest of the three choices.

String Inverters

String inverters are the most common type of inverters used for residential applications, but they can also be used for commercial applications. Most string inverters, also known as wall-mount inverters, range in capacity from 1000 to 11,000 Watts. The name string inverter comes from the way that the inverter system is set up. A group of panels are strung together to form an array. This string is then fed into an inverter, which is usually mounted on a wall near the strings that are fed into it. One benefit to it is the most commonly produced inverter there are many choices for this option. Another benefit is that having inverters with smaller capacities allows for easier integration to existing building electrical systems. Having strings feed into multiple inverters also makes it easier to monitor and troubleshoot compared to a large, central inverter. Although the finding exactly which panel is the problem is not as easy as it would be with a micro-inverter, having stings feed into different inverts can tell the user which string is down. Knowing which string is down can lead to finding which panel, or panels, is the problem. The downside to string inverters is that in order to get more power, there needs to be more inverters. This means that there are more inverters to install, operate, and maintain. Also, at $0.30-0.45 per Watt, string inverters are slightly more costly than central inverters. An example of string inverters is shown in Figure 29.

Figure 28:. String Inverters Example

Central Inverters

Central inverters, also called ground-mount inverters, get their name from the idea that one, centrally located inverter handles the output of all the panels. The inverter is usually located on the ground, because of its large size, near the electric meter. These types of inverters are mainly used for commercial applications, and range in capacity from 10,000 to 500,000 Watts. Having one large inverter handle the entire output of all the panels gives the advantage of having only one inverter to operate and maintain. Central inverters also have the lowest cost per watt of the three options at approximately $0.20-0.40 per Watt. The downside to central inverters is that with all the stings feeding into the one inverter it will be difficult to monitor the output of the different strings, which would make it difficult to determine if there is a problem with one or not. Another disadvantage to having a central inverter is that for Rehoboth new DC lines would have to be run to the central inverter which would be located near the meter. An example of central inverters is shown in Figure 30.

Figure 29: Central Inverters Example

Decision Considerations

Purchase Cost

In order to provide the maximum value to Rehoboth Christian School, the inverter team aims to select the lowest cost inverters, while still ensuring efficient and reliable performance. The metric used to compare costs is purchased cost per watt. This allows for comparison between different inverter types, and the costs per watt are compiled in Figure 27. Other equipment required for tie-in with the grid is selected with cost per watt consideration in addition to compatibility with the building's electrical system and safety considerations.

Installation and Maintenance

Installation and wiring will be the biggest costs for the inverters. Mounting them in their designated locations and running all the necessary wiring can be expensive. The biggest maintenance need will be checking the monitoring system to make sure everything is well connected and performing well. The rest of the electrical equipment requires no maintenance, and should perform flawlessly for the life of the system.

Efficiency

To maximize the output of the solar PV system, the inverter team aims to maximize the efficiency of each component. This mainly affects the inverter selection process and the wire sizing, particularly the AC wiring. The importance of this is to reduce the necessary panels to produce a certain amount of electricity.

Grid Connection

While many large-scale PV systems are standardized for 3-phase power connections, such inverters can limit the flexibility of the installation. The inverter team will make inverter choices to maximize flexibility and compatibility of the installation with whatever electrical system is available. String inverters, while being mostly single-phase, can be wired to function well with three-phase systems. This maximizes the flexibility of the installation, and allows for reconfiguration if necessary.

Appendix III-B. Grid Tie-In

Requirements

The Rehoboth community currently gets its power from Gallup Joint Utilities (GJU). Before the solar installation can begin, GJU has an agreement that lays out the requirements for the solar system that need to be met. The first stipulation that GJU has is that the system is limited to 75 kW. After talking with the utility company, this stipulation has been determined to be negotiable. According to the agreement, the solar installation needs to be inspected by the States Construction Industries Depart (CID). After the inspection, the approval form needs to be signed by both CID and GJU. Also part of the agreement is a clause that says that GJU has the right to terminate the agreement within 30 days written notice for any reason. Included in the agreement are two appendices that give more requirements for the system. The first appendix states that the system must comply with UL standards, any applicable IEEE standards, the 2005 National Electric Code, and any state and local codes and regulations. The appendix states that prior to the installation of the system the above mentioned agreement needs to be executed and all applicable permits must be obtained. Also, prior to connection the system must be inspected by CID and GJU.

It also states that the inverter must be anti-islanding and its power quality must be inspected. Anti-islanding refers to a function of the inverter that shuts the inverter down when the grid goes down in. This function keeps power from being sent out to the grid while it is being worked on. AC current can range from a wave that is like a square (square wave) to a current that has a sinusoidal form. The closer the current is to the sinusoidal wave, the better the quality of the power that is being transmitted. GJU also requires that there is an accessible, manual, lockable load break disconnect switch between the inverter output and the connection to the grid. There should also be a permanent, weatherproof diagram of the system at the metering point. The first appendix addresses net metering as well. It states that once the agreement has been executed, the application for net metering can be made. The excess energy from the system will result in a credit from GJU that will be carried over from month to month. This means that any excess energy, in kWh, that Rehoboth generates will be applied to the next month's bill, and potentially the month after that if the previous energy is more than what was consumed. GJU also states that it has the right to reconcile the account annually by buying back the credits. The second appendix deals with any liability issues that might be brought against GJU. It states that GJU is not responsible for any damage that may be caused to the system for any reason.

Equipment Required

In addition to an inverter and the protection on the DC side, a load center, AC safety disconnect switch, and wiring and conduit are required to tie the system into a building's existing electrical system. A grid tie-in diagram is shown below in Figure 30. The load center functions as a combination point for the power inputs from the various inverters. In essence, the inverters can be viewed as appliances that must be adequately connected to a power source to perform. Just as one would wire multiple power-consuming circuits into a load center, the inverters are wired to the load center to interface with the existing power system. For a three-phase load center, the recommendation is to connect inverters in load-balanced groups of three, one on each 208-volt phase. This enables the system to handle the maximum amount of power for the lowest cost. In the diagram below, the load center is not depicted, as the system only includes one inverter.

The AC disconnect is required by Gallup Joint Utilities to allow for disconnect of the PV system in the event that work must be performed on transmission lines. In addition, it is recommended that a second AC disconnect is included to allow for easy work on an inverter. Assuming that inverters are located on a parapet, or other non-utility-accessible location, it would be very inconvenient to walk down to the utility disconnect in order to perform work on an inverter on the roof. Therefore, it is recommended that a second disconnect is purchased for each load center.

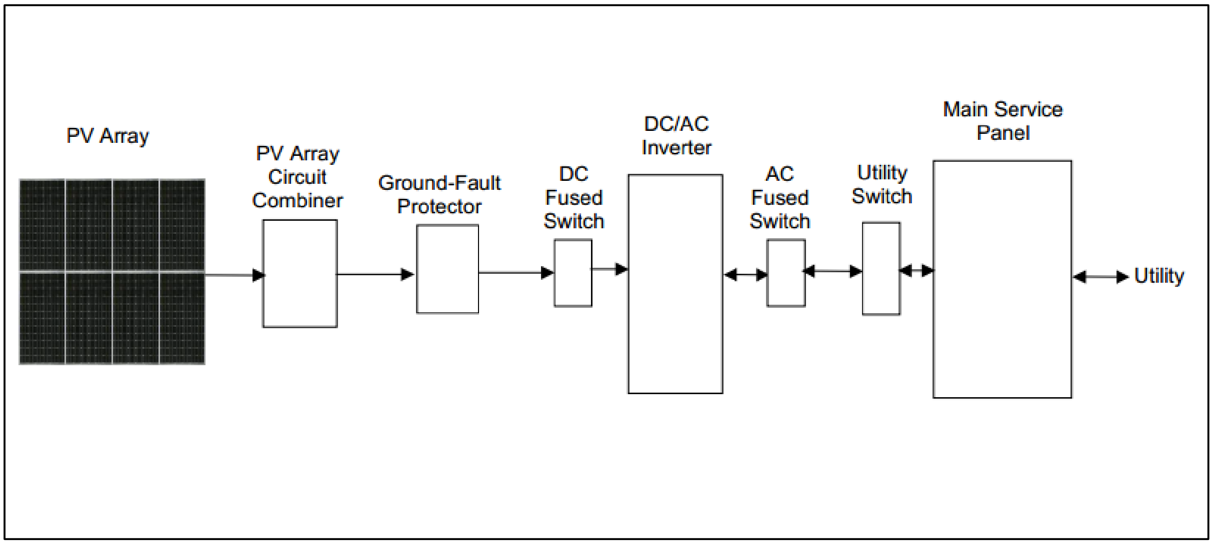

Figure 30: Grid Tie-In Diagram

Appendix III-C. System Monitoring

PV system monitoring is vital to ensure that the expected energy yields are produced. Monitoring systems from Deck Monitoring, SMA Solar Technologies, Also Energy, and Consolidated Solar Technologies were researched. The homepage of a sample monitoring system is shown below in Figure 32. The team prefers Deck Monitoring, but recommends Rehoboth use whatever the installer recommends.

Figure 31: Homepage of Sample Monitoring System

Appendix IV. Financial Analysis

Summary

Introduction

The financial team was primarily responsible for understanding and proposing a financing option for the before mentioned solar system.

Procedures

The financial team for the Rehoboth project consisted of three members: Allen Bosscher, Karl Bratt, and Jonathan Haines, all senior engineers seeking a degree with a mechanical concentration. The team decided that dividing up the necessary financial tasks that needed to be completed for this project was the best method, and therefore assigned each member leadership over these tasks. Allen was assigned as the primary researcher on tax incentives, grants, and financing options. Karl was assigned as the primary researcher of necessary rates as well as the primary creator of the financial team's spreadsheet. Jonathan was assigned as the primary researcher into the electricity bills provided by Rehoboth, as well as the primary person in charge of researching similar projects in the surrounding area.

In addition to these tasks, team members were assigned broader responsibilities, which were further solidified as the project progressed. Karl served as the primary coordinator, both with other teams and with accumulated resources. Jon served as the primary data analyst and team scribe. Allen served as the primary PowerPoint creator, leaving him responsible for combining all of the financial team's research into a concise presentation.

Customer Contact

As mentioned previously, Karl served as the primary coordinator between the financial team and the other teams, as well as with the customers and accumulated resources. The financial team, in cooperation with the other Rehoboth PV project teams, communicated with the ultimate end customer for this project, Jeff Banaszak, on several occasions, as the need dictated. Jeff Banaszak is the Director of Operations at Rehoboth Christian School, meaning that the decision on whether to move ahead with a solar PV system at Rehoboth was ultimately left up to him. Therefore it was the financial team's job to present the research to him so that he could make an informed decision. The team's first communication with Jeff primarily sought to comprehend his needs and wants for this project. This information was helpful in understanding the scope of the project. Additional communication with Jeff were coordinated with the other teams and primarily were set up to answer questions that arose as the project progressed. Additional communication was established with several other resources. Of particular interest to the financial team were the contacts established at Gallup Joint Utility, Consolidated Solar Technologies, and Positive Energy Solar.

Communication with Other Teams

As mentioned previously, Karl served as the primary coordinator between the financial team and the other teams. This means that he worked closely with other groups, coordinating times with other teams to discuss future plans and resource communication.

Results & Conclusion

Taking into account the following system specifications, the team forecasted the thirty year cash flows for each financing option (see Figure 33). As shown, the breakeven point for a directly purchased solar system is approximately twelve years, while that of a school-owned L.L.C is ten (due to the available tax incentives for Limited Liability Corporations). In contrast, there is far less liability associated with both the PPA and solar lease options, due to no upfront costs. While the annual costs associated with these options are higher, all four financing alternatives seem to converge after twenty three years. One thing to note is that there is the option to purchase back the solar panels during the duration of the solar lease or PPA contract, so that after twenty-five years, the school may have full ownership.

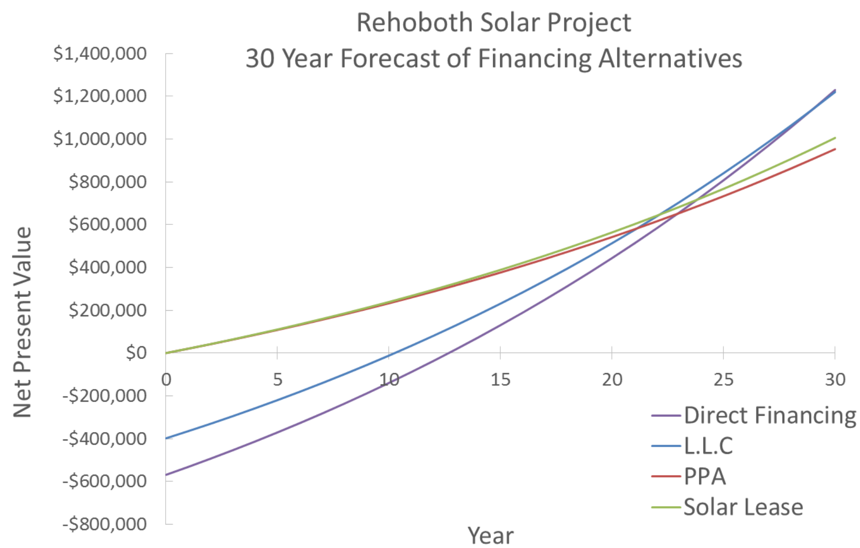

Figure 32: 30 Year Forecast of Cash Flows

Another way to consider this data is by analyzing the average cost of energy associated with each option. By dividing the net present value of expenditures by the total kWh's produced over a twenty-five year warranty lifetime, one cans see that an L.L.C. or solar lease are the best options for financing a solar system at Rehoboth Christian School (see Figure 34).

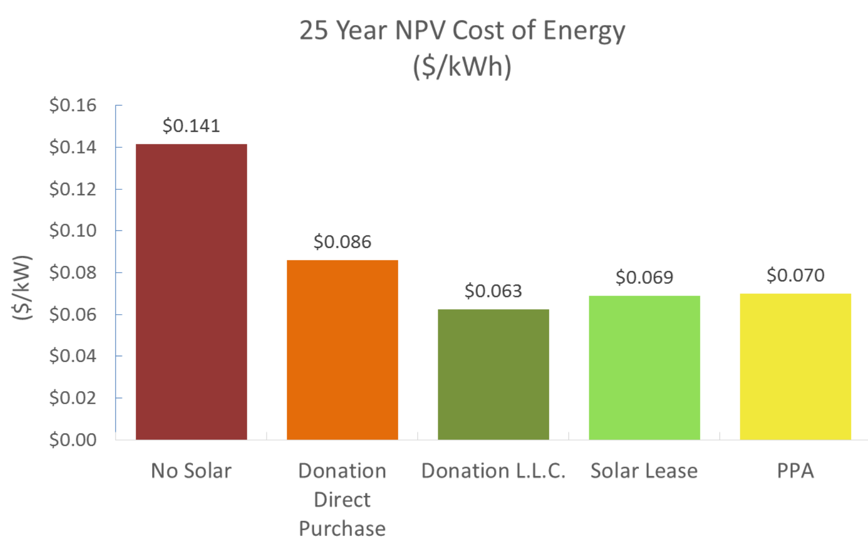

Figure 33: 25 Year NPV Cost of Energy

Appendix IV-A. Payment Options

Several options were considered for paying for the system. These options are explained below in detail.

Direct Financing

Direct financing is a method of payment where Rehoboth would take on all the costs of the solar panels and installation. The benefit of buying the panels outright is that Rehoboth would not need to share the profits with a third party as would happen in some of the options below. The disadvantages though are that first of all, since Rehoboth is non-profit, they cannot take advantage of the federal and state tax incentives which would take off around 30% of the total cost. Because of this, the team has decided that without further financial assistance Rehoboth should not pursue buying the panels directly.

L.L.C.

One option for financial assistance would be for Rehoboth to create an L.L.C. in order to take advantage of the tax incentives. Doing this however would require hiring a lawyer and additional personnel in order to maintain the L.L.C.

Donation

Another option to consider is to raise donations on the premises that after the system pays for itself, the additional money that would be saved would put back into the school. Doing this would eliminate the need to take out a loan and make loan payments. This option also gives the opportunity for donors to get involved with this solar project.

Power Purchase Agreement

A power purchase agreement (PPA) is a contract signed with a larger company. The company agrees to come in and install solar panels on Rehoboth's property, and Rehoboth agree to pay the company for the power produced by the solar panels at a lower rate than what Rehoboth is currently paying. The advantages to this type of agreement are that the company would own and maintain the solar panels resulting in zero upfront cost for Rehoboth, also since the company installing the panels is for profit, they can take advantage of the tax incentives. Some concerns with a PPA are that the contracts that are signed are typically 20 year agreements, and since Rehoboth doesn't actually own the panels, removing or altering the panels is not allowed. The team contacted Patricia Mattioli at Consolidated Solar Technologies who is a specialist in school solar installations in the surrounding area. Patricia mentioned that a PPA would not be feasible for Rehoboth since this type of financing typically looks for systems that would reach a 400 MWh minimum. Since the proposed system is less than 300 MWh, a PPA would not work for Rehoboth.

Solar Lease

A solar lease is similar to a PPA, except that Rehoboth would pay the company to rent the panels at a fixed rate. The advantages to this type of agreement are that the company would own and maintain the solar panels resulting in zero upfront cost for Rehoboth, also since the company installing the panels is for profit, they can take advantage of the tax incentives. Some concerns with a solar lease are that the contracts that are signed are typically 20 year agreements. The team contacted Patricia Mattioli at Consolidated Solar Technologies who is a specialist in school solar installations in the surrounding area. Patricia Is currently working on putting together a package with information regarding rates and payment options for a solar lease.

Appendix IV-B. Incentives & Grants

Incentives

The financial team determined that researching available state and federal incentives in order to finance this project was a critical portion of the overall project. Through the assistance of one of the team's supporting resources, Chuck Holwerda, the team learned that the Database of State Incentives for Renewables and Efficiency (DSIRE) was a great website to provide all possible federal and state incentives. Their website, dsireusa.org/solar/, compiled all of these possible incentives in an easy to understand way.

Federal

The financial team discovered that there were no possible federal incentives that Rehoboth Christian School could pursue. However, were the project to form a commercial "shell" company to operate through, it could be eligible for the Business Energy Investment Tax Credit (ITC). This corporate tax credit is applicable to the commercial sector, and would credit the corporation with a tax credit equal to 30% of the total expenditures, with no maximum credit. However, forming a shell corporation with the express purpose of receiving this tax credit could prove challenging, especially to a nonprofit Christian school. Figuring out how to create and run this corporation would invariably require lawyer assistance, and could prove to be more trouble than it is worth. This decision will need to be ultimately determined by Jeff Banaszak and the board at Rehoboth Christian School. Rehoboth could also use creative financing methods, such as power purchase agreements or solar leases. These options would allow the companies that provide the photovoltaic systems to Rehoboth to collect this incentive, passing along the savings to Rehoboth in the form of lower payments.

State

The financial team next looked into possible state incentives that Rehoboth could be applicable to. Similar to the federal incentive, there is a New Mexico corporate tax credit that would provide 6% credit up to $60 million. This would also require a commercial entity to be created, or for Rehoboth to lease the system from an outside company.

The next state incentive researched was the Sustainable Building Tax Credit. This is available to nonprofit entities. The amount varies based on the square footage of the project, as well as the LEED certification level of the project. The tax credit ranges from $0.30 per square foot to $6.25 per square foot. Although nonprofits are obviously not taxed by the state, they can apply for this credit and then sell the credit to an entity that does pay taxes.

Grant Options

One of the most important aspects of this project for the financial team was to research potential grant options that could be pursued by Rehoboth, as a way to offset the initial purchase cost of the proposed solar photovoltaic system. Through the assistance of one of the team's supporting resources, Chuck Holwerda, the team learned that the Database of State Incentives for Renewables and Efficiency (DSIRE) was also a great website to provide all possible federal and state grant options. Through this website the financial team discovered that there were no applicable state grant options, which was in line with the team's expectations. As explained previously in this report, the price of electricity in New Mexico is lower than the national average, mostly due to the great solar potential of the New Mexico area. Since the solar scene in New Mexico has risen dramatically over the past few decades the state does not need to provide grants, as the cost of solar energy has decreased to being competitive with coal powered electricity. Solar photovoltaic systems have become so common place and cost effective in New Mexico that grants are not even being offered at the state level.

The financial team then researched federal grant options for the photovoltaic system. The DSIRE showed that there were only three federal grant programs that were applicable to renewable energy systems. One of these options, the Tribal Energy Program Grant, was eliminated very quickly, as it was only applicable to tribal governments. The next grant option, the USDA High Energy Cost Grant Program, seemed like an acceptable option, as it was applicable to the nonprofit sector. However, the High Energy Cost Grant is aptly named; as eligibility is limited to projects in communities that have average home energy costs at least 275% above the national average. Unfortunately, the average home energy cost in New Mexico is actually below the national average, eliminating this grant program from being an option.

The final grant program, the USDA Rural Energy for America Program (REAP) Grant, was deemed to be the only possible grant for this project. Schools were once again an applicable sector, however through further research the financial team discovered that schools were defined in this grant to refer only to colleges and universities, and not to K-12 schools. Since Rehoboth Christian School is a K-12 school it is therefore not a possibility for this grant. However, if the project was to create a LLC or use other creative financing method and form a corporation with commercial ties, this grant could still be an acceptable option. If the project is structured with this in mind, the grant would be able to pay for 25% of the total project cost, up to $500,000.

Appendix IV-C. Electricity Bill Research

Gallup Joint Utilities

After looking at the bills from Rehoboth, it was discovered that Gallup Joint Utilities (GJU) supplied Rehoboth community with electricity. GJU is one of the largest municipal utilities in the state of New Mexico. Since they are municipal however, they do not offer incentives to switch to solar power since they are not required to hit a certain percentage of sustainable power production as some of the larger utilities are required to do

Initial Analysis

Electric bills dating back to June 2012 were obtained and put into Excel for analysis. The columns that were included were consumption, cost of electric, total cost, and peak consumption. It was found that Rehoboth used 600,000 kWh annually with a peak consumption monthly average of 158 kW. I was discovered that Rehoboth was incurring rate charged for exceeding the peak rate of 100 kW.

Discussion of Charges/Surcharges

The financial team found that there are four main areas of charges from Gallup Joint Utilities. The monthly electric bill consisted of the additional demand charge, the usage surcharge, environmental surcharge, and the cost per kWh. The financial team reasoned that it would be beneficial to research in depth on each of these areas, in order to better understand Rehoboth's electric bill. The figure below shows the monthly projected energy bill for 2014, with the four sections separated.

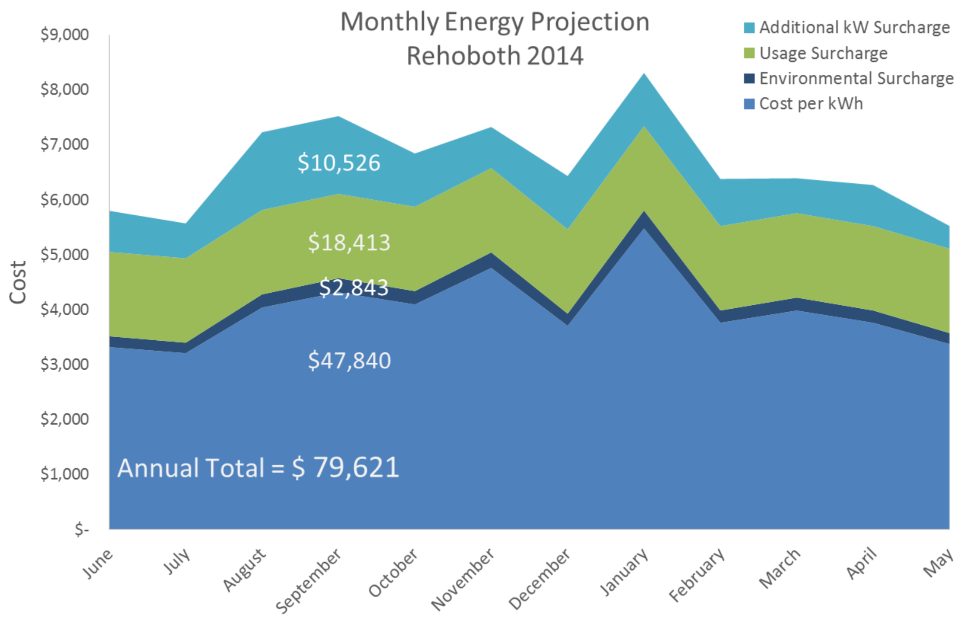

Figure 34: Projected Monthly Energy Bill

The first electric bill section researched was the additional demand charge. The financial team found this section of the bill to be the most intriguing, as the cost seemed astronomically high. This cost is incurred whenever Rehoboth Christian School exceeds 100kW at any point in a month, for any duration. The maximum kW over 100 for each month was then charged at $15.9/kW. For example, if Rehoboth drew 150kW peak energy usage at any point during last month they would then have to pay $795 ($15.9/kW * 50 kW). The team discovered that Rehoboth Christian School exceeded 100kW peak consumption for every month for which the team was provided data. This incurred roughly $9,000 in annual additional demand charges. This is a large portion of the annual bill which would be greatly reduced if a photovoltaic system was implemented. Additionally, the team recommends that energy saving programs be created at Rehoboth, as this peak consumption could most likely be greatly reduced through simple energy reduction methods. This additional demand charge accounts for roughly 13% of the annual electric bill, so reducing this cost would be very beneficial for Rehoboth.

The second electric bill section is the usage surcharge, which exists simply due to the tier in which Rehoboth is a part of. Rehoboth is currently in the General Service Medium tier, which is explained in detail below. Since Rehoboth's energy demands place it in this tier, they are required to pay the monthly usage surcharge of roughly $1,500. This usage surcharge accounts for roughly 23% of the annual electric bill. This is a non-trivial cost, and would be effectively eliminated were Rehoboth to drop down into the General Service Small tier.

The third electric bill section is the environmental surcharge. This is a surcharge that is more based upon Gallup Joint Utilities' policies than Rehoboth's energy consumption. The environmental surcharge is a cost that Gallup Joint Utility must pay to the federal government and is based upon their sources of electricity. The environmental surcharge accounts for roughly 4% of the annual electric bill. This surcharge is a very small portion of the overall electric bill, and since it is not directly controlled by Rehoboth it was not looked into great depth.

The final electric bill section is the cost per kW. This is the standard cost that most associate with electric bills, as it is a flat rate for electricity in cents per kWh. This is by far the largest section of the monthly electric bill, and for Rehoboth comes out to $0.0791/kWh. This section of the electric bill accounts for roughly 60% of the annual electric bill, so offsetting the purchased electricity through a photovoltaic system would be advantageous from a cost standpoint.

Discussion of Tiers

Through researching the electric bills for Rehoboth Christian School, the financial team discovered a potential issue for this photovoltaic project. Rehoboth is currently in the General Service Medium Tier at Gallup Joint Utilities due to their monthly energy needs. Rehoboth will remain in this tier as long as they use 40,000kWh/month or use over 100kW at any time during a month, for three consecutive months. Rehoboth currently meets both of these requirements easily, as they go over the 40,000kWh/month nearly every month, and draw over 100kW every month for which the team received data. Remaining in this tier results in a monthly surcharge of roughly $1,500 which was mentioned earlier in this report. Additionally, Rehoboth has to pay the additional demand charge for going over 100kW at any point in time, also mentioned earlier in this report.

If the photovoltaic system offset enough energy demand to go below both requirements for three consecutive months, then Rehoboth would be dropped down into the General Service Small tier. This tier has a higher energy charge, $0.1285/kWh, but has a monthly surcharge for the first 100kWh of only $14.45, which is much lower than the roughly $1,500 monthly surcharge for the General Service Medium tier. The increased rate was initially a source of concern for the financial team, but upon further review the differences between the rate tiers are much less concerning, especially when considering the low electric rates possible through power purchase agreements or solar leases.

Future Implications

The team was provided with the most recent electric bills from Gallup Joint Utility, which displayed the most up to date electric rate. Using this data, as well as data from the past decade, the team was able to determine growth rates for the cost of electricity. With these growth rates the team was able to predict the future trend of electricity cost for Rehoboth Christian School. This projection is shown in the figure below.

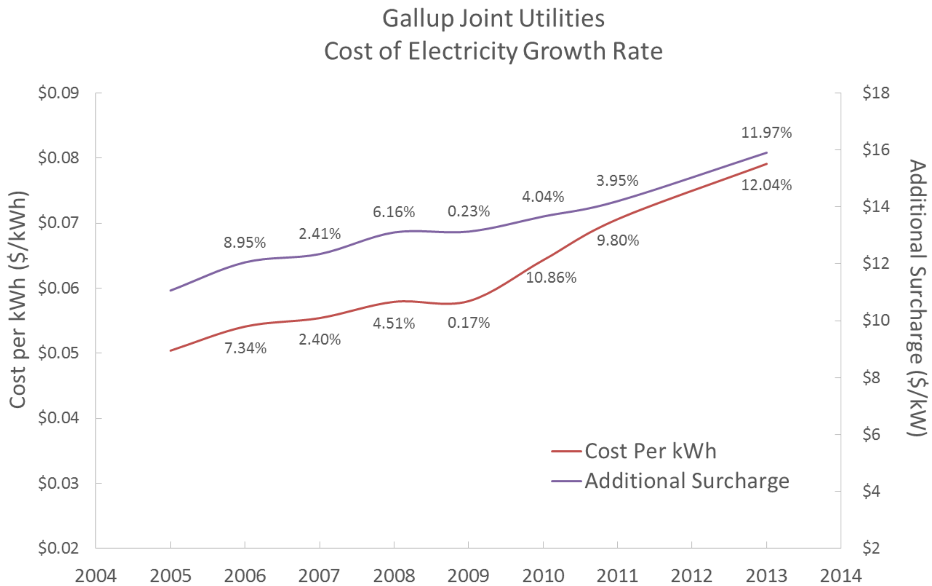

Figure 35: Electricity Growth Rate

From this figure, it is clear that the cost of electricity will continue to rise, further solidifying the idea that a photovoltaic system would be beneficial for Rehoboth from a cost standpoint. Signing a power purchase agreement at a flat rate for twenty years would allow Rehoboth to achieve larger than initially expected savings with this growth rate in mind.

Split Metering

The financial team discovered that there is a potential issue with the structure of typical solar agreements with Gallup Joint Utilities. There is a limit written into the contract that states the maximum solar generating system that would be approved by Gallup is a 75 kW system. Gallup Joint Utilities seemed to be fairly set at this number, and expressed significant issue with our suggestion of seeking approval for a 200 kW system.

Additionally, the financial team learned that Gallup Joint Utility is moving forward with a split metering system, meaning that there will be more than one account for Rehoboth Christian School's energy consumption. This will result in a larger combined monthly bill due to the usage surcharge that would be present in each separate account. The financial team has factored this consideration into the financial spreadsheet, but unfortunately realize that this policy will be enacted regardless of Rehoboth's desires.

Appendix IV-D. Cost Models & Forecasting

Creation

The team structured an Excel workbook to model the net present value of cash flows for each financing alternative. With a few given inputs, the workbook will project economic payment time in years.

Inputs

The goal behind forecasting the cash flows of each alternative was so that a user could change out components in the system and observe the effects of those changes on its overall cost and payback. In addition, the team hoped for adaptability in how the growth rate assumptions were modeled into the net present value calculations.

Rates

Table 5 describes assumptions of the annual inflation, discount, cost of energy, and panel degradation rates over the projected lifespan on the solar panels.

Table 5. Annual Growth Rates

Annual Growth Rates (%)	
Inflation	2.81%
Discount	4.50%
Cost of Energy	4.95%
Panel Degregation	0.25%

The inflation rate is the twenty-five year average of the Consumer Price Index published monthly by the United States Bureau of Labor Statistics (BLS).[3] The discount rate is the average discount rate used by firms to forecast the future net present value of the dollar.[4] The cost of energy is the average growth rate of energy demand charges by Gallup Joint Utilities (see Figure 36). Finally, the panel degradation rate was found to be 0.25% based on studies by SunPower and outside resources.[5]

Cost Estimates

In addition to growth rate, additional educated estimates were made on the system costs in terms of $/kWh and $/W capacity, as shown in Table 6.

Table 6. Cost Estimates

Cost Estimates ($/kWh)	
Current	$0.133
PPA	$0.07
Cost Estimates ($/W)	
Solar Lease Monthly Payment	$0.01
Installation Cost per Watt	$1.68
Mounting Cost per Watt	$0.12

$0.133 was used as the cost of energy because this reflects the Gallup Joint Utility General Small rate tier. If the school is to implement the proposed solar system, it will fall into this new rate schedule. $0.07 was used as the PPA cost of energy based on estimates provided by Consolidated Solar Technologies in Albuquerque, NM. A solar lease monthly payment of $.01/W was used while the team waits upon a more accurate quote from Consolidated Solar, to be sent on January 30. This figure came from estimates found word-of-mouth and online. In regards to installation and mounting costs, Appendix I. Site Selection has gone into further about the origin of these values.

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[3] http://www.usinflationcalculator.com/inflation/historical-inflation-rates/
[4] http://www.impactdatasource.com/choosing-a-discount-rate
[5] http://bit.ly/1mIuq52

Outputs

To estimate the total costs and energy production of the system, the system specifications of the proposed panel locations were consolidated, as seen in Table 7.

Table 7. Location System Specifications

Option 1: Band Room & Fitness Center	
Number of Panels	240
Electricity Production (kWh/yr)	136900
Peak Energy Production Rate (W)	78480
Option 2: New High School Flat Roof	
Number of Panels	272
Electricity Production (kWh/yr)	154600
Peak Energy Production Rate (W)	88944

By combining this data, the consolidated system specifications were tabulated, as shown in Table 8.

Table 8: Consolidated System Specifications

TOTAL	
Peak Energy Production Rate (kW)	**167**
Cost per Watt ($/W))	**$3.40**
Estimated Energy Production (MWh/yr)	**292**
Solar Production (%)	**46.8%**

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Mr. Lambert van Poolen– Engineering Professor Emeritus

Mr. Peter Baldwin – AMDG Architects

Mr. Ken Zysltra – Rehoboth Director of Advancement

Mr. Jeff Banaszak- Rehoboth Christian School Coordinator