Designing a Solar Cell Array for the Art and Design Building

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I. Mission

Mission Statement: The mission of this project was to design a solar cell array to be placed on the Art and Design building at the University of Illinois at Urbana-Champaign.

Justification and Motivation: As humanity has become more aware of the effects of fossil fuel use and its role on climate change, it has become increasingly necessary to combat and try to reverse the release of greenhouse gases (GHGs) into our atmosphere. The University of Illinois specifically has become a leader in moving away from the release of GHGs, particularly carbon dioxide, by pledging to become "carbon neutral" by the year 2050 [1]. In order to achieve this goal, significant changes must be made in regard to how the university produces power. Currently, Abbott Power Plant (APP), the university's local source of electricity and heating, runs primarily on natural gas and coal, both fossil fuels that release GHGs upon combustion [2].

It is evident that if the university is to reach its goal by 2050, it must transition away from these sources of power and move to more renewable and carbon neutral sources, such as wind, nuclear, geothermal, and solar. Solar energy is particularly attractive, because it can produce electricity with zero carbon emission, utilize unused and "wasted" space such as rooftops, and is becoming increasingly economically viable. Therein lies the motivation for this design project: if we can put a solar cell array on the roof of a campus building (the Art and Design building being but one possible location), we can generate carbon-free electricity without using any precious free space on the university's property.

Ideally, our design would have a high energy density (power generation per area) because we are working with a rooftop that is limited by space. Additionally, it should be as economically feasible as possible, i.e. having a low total cost and cost per watt or kWh. A detailed list of objectives and constraints can be found in the next section.

II. Design Constraints

Some of our design constraints and design objectives are shown in the Table 1 below.

Table 1:

Goals	Constraint / Objective
Must be able to withstand climate (95 mph wind speeds, -35-45 °C) [3]	Constraint
Must be able to be installed on the Art and Design building with minimal roof penetration	Constraint
Easy to maintain	Objective
Life expectancy of 20+ years	Objective
Easy to install	Objective
Modular design	Objective

The two biggest design constraints for our solar array are being able to withstand the climate of Champaign, IL and the ability for the array to be installed on the Art and Design Building with minimal roof penetration. The Art and Design Building does not have a very sturdy roof that can withstand a lot of drilling or heavy equipment being attached to it. This constraint was also given to us by the Director of Facilities of the Art and Design building because they want to keep damage and alterations to the roof as minimal as possible. The other constraint is being able to withstand the harshest conditions that Champaign, IL experiences. Using data from Weather Underground [3] we were able to obtain the max wind speed and minimum temperatures in the past 6 years. A highest wind speed of 95 mph and minimum temperature of -20 C is what our design needs to be able to withstand and operate in. These two constraints are the most important because they involve the basic functioning and lifespan of the project. The other constraints that were either given to us or that presented themselves naturally in our project are designing the array so that it is easy to maintain, have a life expectancy of at least 20 years, being easy to install, and having a modular design. Being easy to maintain makes this project more attractive for this university to fund. If the design is well made and can be accessed and fixed easily, it will be easier to use in the long run. The life expectancy of at least 20 years comes from the fact that most solar arrays, commercial and industrial, have buyback periods of at least 20 years before they begin to break even. If our design cannot survive until the buyback period then it is considered a financial failure. Being easy to install is also another objective of our design, the simpler and better our design is the easier it will end up being to install. Having a simple installation procedure will also reduce the labor cost. Having a modular design is the another objective that we really thought was important. If we were able to make a modular design that can be adapted to any building on campus, in any configuration, it would make the University's goal of achieving carbon neutral energy production a lot easier. Designing a solar array for one building is a big task, however if the basic design has been agreed upon, the design can be used to fit it to any building and achieve the same level of success.

III. Final Design Concept

Figure 1a: [4]

Miasolé 340W Flex-02

Figure 1b: [5]

Enphase S280 Micro-inverter

The two components used to construct the solar array are the Miasolé 340W Flex-02 panel and the Enphase S280 micro-inverter. The Flex-02 panel is produced with an adhesive painted on the back of the panel eliminating the need for a racking/mounting system. The panel is simply applied and adhered directly to the building’s roof. The Enphase S280 micro-inverter was chosen due to its high input power and smart grid application capabilities. These products met the specific design constraints and ensured the best value per watt.

Key design Aspects:

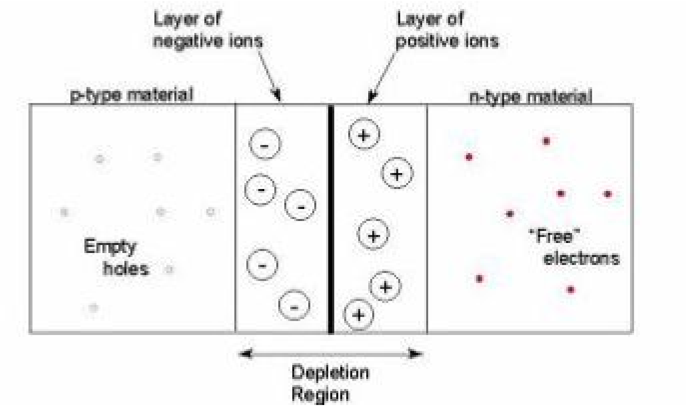
The proposed 136 kW solar array is composed of 400 individual panels and micro-inverters designed specifically for the roof of the Art and Design Building. The panel material chosen for the array was the Miasolé CIGS Flex-02 panel. This panel provided significant advantages over the traditional solar panel materials that reduce installation and component costs and improve the total amount of produced power. Specifically, the panel material chosen eliminated the need for a racking and mounting system that would would reduce the total amount of panels installed and increase the total cost of the project. Enphase S280 micro-inverters were chosen over traditional large scale string inverters. Micro-inverters have inherent advantages over string inverters due to the capability of reducing losses from shading and individual panel malfunction. Micro inverters eliminate the need for large centralized string inverters essentially promoting a modular solar array design that can be easily recreated on additional buildings. Additionally, micro-inverters such as the S280 can be connected to an external grid to provide data and information regarding the performance of each individual panel of the array [5].

Material Selection

Background

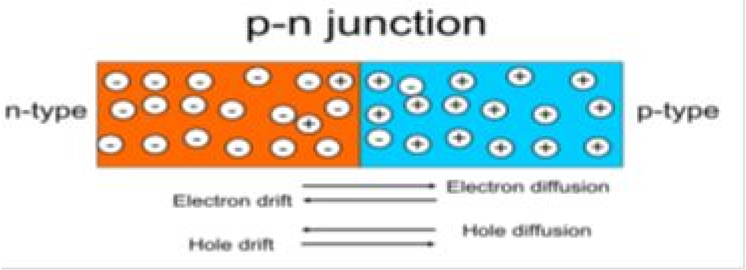
Photovoltaic cells, otherwise known as solar cells, are the result of the fundamental theory behind p-n junctions. P-N junctions, which are a combination of two doped semiconductors, one p-type and one n-type, are formed when the semiconductors are placed into contact with one another. This junction creates a concentration gradient which the electrons and holes in the combined semiconductor follow. Electrons diffuse across the junction from the n-type side to the p-type side, while the holes diffuse across the junction from the p-type side to the n-type side. As the holes and electrons diffuse across the barrier they create individual diffusion currents and leave behind charged donor ions. These charged ions may recombine at the junction interface and form what is known as the depletion, or space charge region. A schematic of the depletion region is shown in Figure 2 below.

Figure 2: [6]



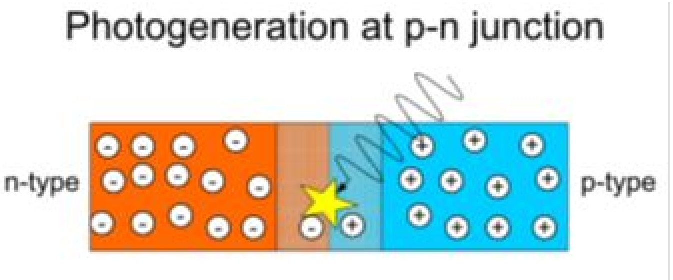
As a result of the differences in the charges in the space charge region an electric field is formed. The electric field acts as a force that opposes the diffusion of the carriers. The direction of the electric field is determined as a result of where the positive charges want to travel. In addition to creating a force that opposes the diffusion of the carriers, the electric field also creates hole and electron drift currents which are directed in the opposite direction as the individual diffusion currents. The diffusion and drift currents as well as the charged donor ions are shown in a p-n junction in Figure 3.

Figure 3: A schematic of the simple p-n junction indicating diffusion and drift currents. [7]



Solar cells are constructed as the result of a particular function of the p-n junction. When light is shined on the p-n junction, the incoming photons will generate electron-hole pairs in the depletion region. These electrons and holes are separated by the electric field and forced into the n-type and p-type sides. Figure 4 depicts the generation process.

Figure 4: A schematic of a simple p-n junction representing the photogeneration process [7]



This process, known as photogeneration, is underlying theory behind photovoltaic cells. Modern photovoltaic cells expand off of the the capabilities of the p-n junction and improve the generation process with semiconducting materials.

Panel Selection

There were four types of materials considered in this project: CIGS (copper indium gallium di-selenide), polycrystalline silicon, monocrystalline silicon, and thin film cadmium telluride. The materials considered were evaluated based on two important factors, total cost of the system and power output (efficiency). The total cost of the system included variables such as individual panel cost, racking and mounting system cost, installation cost, warranty lifetime and inverter cost. Each of the materials considered in this project were analyzed based on these two factors and compared with one another. Table 2 below presents the cost data for each panel material considered. The warranty lifetime is the time period the manufacturer guarantees that the power degradation of the solar cell will not exceed 20%.

Table 2: [4]

	Panel Cost	Mounting System Cost	Installation Cost	Warranty Lifetime	Inverter Cost	Estimated Total Cost (Including 7.5% tax rate)
CIGS	$1.40/Watt	$0	$38,036	25 yrs.	$68,800	$328,334
Poly-Si	$0.96/Watt	$18,000	$58,250	25 yrs.	$68,800	$218,058
Mono-Si	$1.00/Watt	$18,000	$58,250	25 yrs.	$68,800	$239,778
CdTe	$1.75/Watt	$18,000	$58,250	25 yrs.	$68,800	$302,667

The power of the arrays considered was broken down into two separate categories, rated power and efficiency. Additionally, the number of projected panels for each array were included in the estimation of the total power. Table 3 contains the data for each material considered.

Table 3[4]:

	Rated Power (per panel)	Efficiency	Number of Panels Installed	Rated Power of Array
CIGS	340 W	16%	400	136 kW
Poly-SI	260-275 W	13-16%	300	82.5 kW
Mono-Si	200-285 W	15-20%	300	85.5 kW
CdTe	200-285 W	14.5%	300	85.5 kW

The first material eliminated from consideration was the cadmium telluride panel due to the high cost of the panel coupled with the low efficiency rating and purchase availability. Additionally, the toxicity of cadmium was a long term environmental concern. The remaining materials considered were further reduced to the polycrystalline silicon panel and the CIGS panel. Monocrystalline silicon panels were removed from consideration due to the similarities that lie between monocrystalline and polycrystalline panel performance. The materials were rated with very similar efficiencies and cost per watt, however, the polycrystalline panels were more readily available for purchase and are the current industry favorite. The final material selection was determined as a evaluation between CIGS panels and polycrystalline panels. CIGS panels, in particular, provided many advantages over the traditional polycrystalline panels due to the inherent properties of the flexible panel. Table 4 below shows many of the advantages of CIGS panels.

Table 4: A comparison between CIGS and Poly Si panels [4]

	CIGS	**Poly Si**
Structure	● Flexible (can conform to to curved structures)	● Rigid
Racking	● No requirement for racking	● Requires racking
Durability	● Will not break ● No risk of microcracks	● Can shatter ● Can develop microcracks
Mounting	● Can be bonded directly to roof surface ● Lower installation costs	● Requires mounting/ racking hardware ● Higher installation costs
Wind Resistance	● Thin structure (2mm -	● Thicker (40 mm- 50

	3mm) provides superior wind resistance	mm) Allows it to be subjected to wind uplift
Power	- Greater watt per mass (340-360 W)	- Traditional 260-275 W
Safety	- Lightweight, no cell degradation at high voltages, no grounding wires to corrode	- Metal racks and box modules can harm people and damage property. Also subject to wind damage

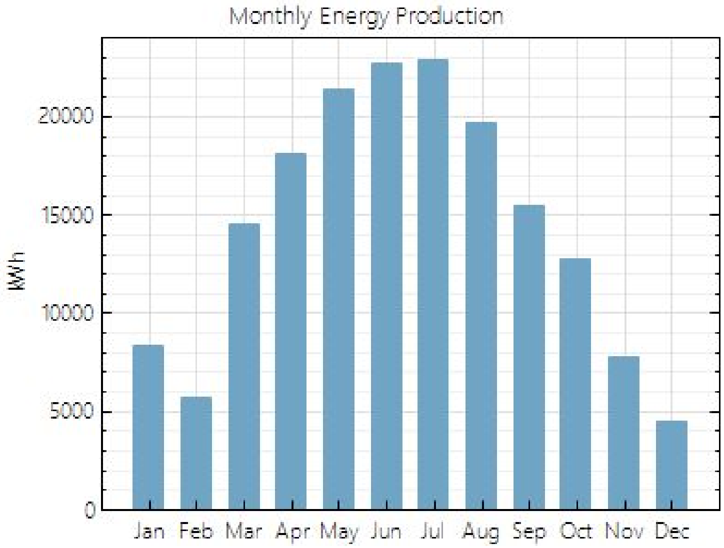
The panel chosen for this project was the CIGS 340 W Flex-02 solar panel produced by Miasolé. This panel provided the greatest cost per watt value and power per area.

Inverter Selection:

Micro-inverters were chosen for this array due to the particular advantages they provide. As stated previously, microinverters reduce losses from shading and malfunctioning panels since they are individually isolated from the array. Additionally, the microinverters can be designed to import panel performance data into a remote server. This is particularly valuable as both performance data and panel health can be monitored continuously. Currently, Enphase is the domestic market leader in manufacturing high quality micro inverters. The micro inverters produced by Enphase are offered with a 25 year warranty in contrast to the standard ten year warranties offered with centralized string inverters [5]. A 25 year warranty is consistent with the warranty for the panels selected for this array eliminating the potential complication of replacing inverters before complete panel degradation.

Power Analysis

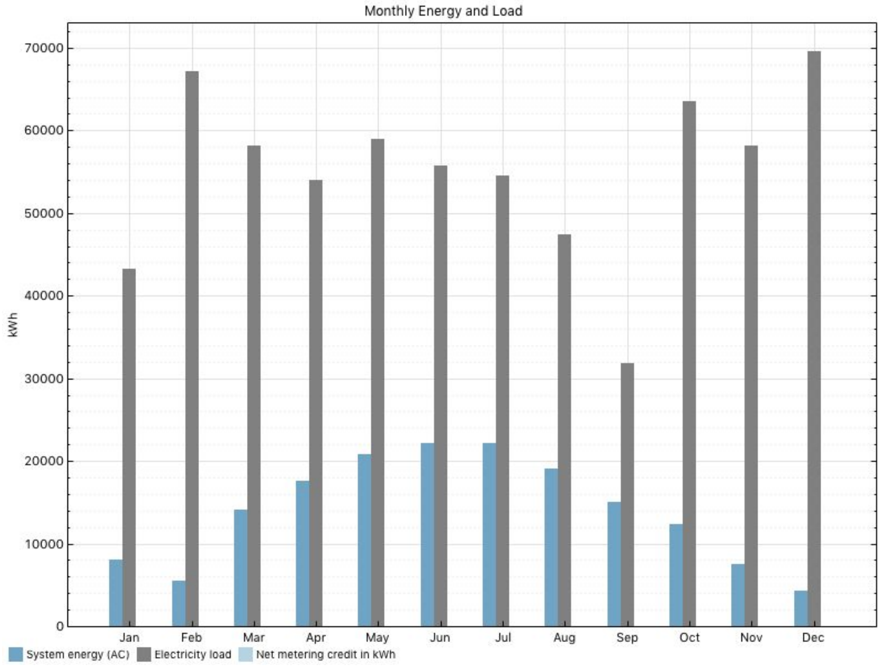
Perhaps one of the most important aspects of our final design to focus on is the power analysis, i.e. what is the total power output per year, how the output varies throughout the year, and how well our panels are performing. This can be done relatively easily through the System Advisor Model (SAM) provided by the National Renewable Energy Laboratory (NREL). By inputting the specifications of our array, particularly the solar modules, microinverters, and size, as well as using provided weather files, SAM was able to simulate how our array would perform in the real world. Predicted monthly energy production, in kWh, of our array can be found below. ***Figure 5:***



It is somewhat obvious that the performance of our array will decrease throughout the winter months, particularly due to snow coverage. At a low tilt, snow does not leave their surface as easily as a module at 45°. This is more than made up for, however, in the summer months. Overall, SAM predicted that the annual yearly output of our 136 kW array would be about 174

MWh, with a performance ratio of 0.83. The performance ratio measures how much energy is actually produced by our array in a given year relative to how much would be expected to be produced given the nameplate capacity of our array. In essence, it takes soiling, weather, wiring, conversion and other losses into account. SAM predicts that the bulk of our losses will be due to the former four listed. Our array will produce enough power to offset roughly 26% of 2015 power consumption by the Art and Design building. In perspective, the annual yearly output of this array is enough to offset the standard energy consumption of approximately 16 single family American homes [8]. If the building increases efficiency in its power usage, this percentage could increase further. The predicted monthly energy production of the array against the monthly energy consumption of the Art and Design building for 2015 is shown below in Figure 6.

Figure 6:



Cost Analysis

One of the most compelling reasons for choosing the CIGS panels over traditional polycrystalline silicon panels is the simplicity of the installation. While CIGS panels are expensive compared to their silicon photovoltaic counterparts, they do not require racking for installation. Essentially, this translates to a lowered cost of installation. In order to obtain a realistic estimate for final project costs, a recent quote and a contact from Glesco Electric Incorporated in Urbana, IL was consulted to achieve the most industry accurate estimations. It is of note that the following calculations for the proposed final design was made with upper limit estimates; leading us to believe that the actual finalized cost of our array will likely be lower. For reference, the Glesco quote for the University (Circa: October 2015) for a 72 panel, 19 kilowatt polycrystalline array is tabulated below on Table 5 [9]. This quote included fixed costs such as the cost of crane usage, the cost of professionally approved drawings, materials, and labor (which included rooftop installation, a tie-in to both the sub-panel of the building and the University of Illinois communication network, and a power monitoring station installation).

Table 5 [9]:

Items	Costs
Labor (224 Hours of Labor at $91.43 / hr)	$20,481.00
Crane	$1,500.00
Stamped Engineering Drawings	$5,000.00
Materials	$38,354.00
Total	**$65,335.00**

The items in red are the fixed costs within the quote.

The costs for the array were first split into fixed costs and variable costs. Fixed costs were defined as the installation costs that would not change whether the University decides to install a single panel or four hundred. This includes rental for a crane, approved engineering drawings, and the electrical work needed for installing the auxiliary equipments, such as tying the rooftop array to a sub-panel of the building, installing a smart monitoring system, and connecting the monitoring system to the University of Illinois network. The contact at Glesco electric disclosed that a traditional silicon array takes approximately 1.5 hours to install per panel: meaning that it would take 1.5 hours in order to have one panel installed with a microinverter on the roof on racking with a ballasted counterweight and conduit installation (including craning for the items). Basing our calculations off of that value and the quote, the fixed cost labor involved was back calculated. Since the labor was quoted as 224 hours, 108 hours - the hours necessary to install the actually array on the rooftop - was subtracted from this value. This led us to a value of approximately 116 hours of labor needed for the array, independent of the size of the actual array. Assuming the rate of $91.43 per hour for labor, the work needed for this portion of the installation comes to $10,606.

In terms of variable costs, the two costs associated with a solar array is the cost of installation and the materials needed for the installation. A representative at MiaSole disclosed that a typical cost for their FLEX-02 panels could accurately be estimated as $1.40 per watt; thus, a single 340 watt panel would cost ~ $475. The Enphase S280 microinverter used in our design was found through an online distributor at ~ $160 each. An additional $10,000 was allocated for wiring, conduits, and the power monitoring system. Scaling these costs for a 400 panel system, and factoring in a 7.5% tax rate, resulted in a total material cost of ~ $283,800.

Rooftop installation labor was calculated by information from case studies conducted by MiaSole. On average, it was found that a flexible panel installation was, on average, 50% less than traditional racked arrays. Using the 1.5 hours per panel estimate from Glesco Electric, 45 minutes per panel was assumed for the flexible panels [10]. When scaled for a 400 panel installation, 300 hours of labor was estimated, or ~ $27,430 at an hourly rate of $91.43 an hour.

In total, the final expected cost for the 400 panel array comes to $328,334 or $2.41 dollars per watt. The final cost estimates for the final design are tabulated below in Table 6.

Table 6:

Items	**Final Design**
Labor for Rooftop Installation (300 hours)	$27,430
Auxiliary Electrical Work (116 Hours)	$10,606
Crane	$1,500
Approved Engineering Drawings	$5,000
Materials	$283,800
Total Cost	**$328,334**
Dollar per Watt	**$2.41**

The items in red are the fixed costs associated with installation.

Environmental Impact and Sustainability

Sustainability was a driving factor in the motivation for designing a solar cell array on campus, especially given the iCAP pledge for the university to become carbon neutral by 2050. It is therefore useful to calculate the offset of carbon dioxide and other GHGs that will not be released into the atmosphere by generating our power using solar instead of fossil fuels. APP releases CO_2 at a rate of 0.87 lbs/kWh of power generation, while electricity purchased by the university releases CO_2 at a higher rate of 1.6 lbs/kWh [2]. This is attributed to better efficiency and scrubbing at APP, and its higher use of natural gas over coal. If our array generates roughly 174,000 kWh in a given year (predicted from our SAM model), the amount of carbon dioxide prevented from entering our atmosphere will be somewhere between 76-139 tons, depending on what percentage of electricity offset would have been produced by APP vs. purchased as supplementary. This is a significant amount of carbon dioxide savings. While small compared to the billions of tonnes released annually by mankind, but it is a step in the right direction and is particularly useful to the university given its carbon neutrality pledge.

IV. Benchmarking

Benchmarking of a solar cell array is heavily determined by the cost analysis of the array, discussed above. Ultimately, the cost per Watt is how one array is compared to the next. It is, however, useful to compare our designed array to other arrays in the Champaign-Urbana area. These comparisons can be made between cost per Watt, total cost, total energy output, and payback period. Equally useful is to compare our design, which uses CIGS, to a typical array that uses poly silicon (Poly Si), which is the dominant technology currently on the market. In the following examples, we used the Astronergy VIOLIN II 265W module [11]. This can justify our choice of material.

There are a number of solar cell arrays currently in the Champaign-Urbana area, including the BIF array, the array built by MTD, and the newly completely Solar Farm at the south of campus. A compilation of important solar parameters of these different arrays, compared to our design, can be found in Table 7. As it can be seen, our array compares very well for one of its size, providing a cheaper cost per watt compared to other medium-size rooftop arrays. The only one it cannot compete with is the Solar Farm, which, due to its immense size, can drive down cost per Watt. Our design's total cost is also quite low for its size.

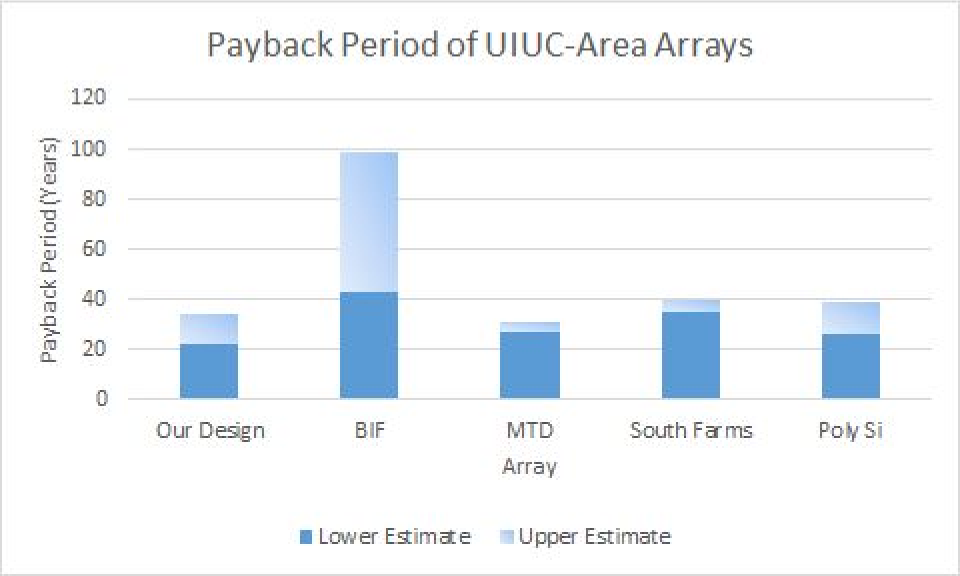
Table 7:

Property	Our Design	BIF [12]	MTD [13]	Solar Farm [14]
Year Built	N/A	2005	2013	2015
Total Cost ($)	328,334	245,663	900,000	15,500,000
Output (kWh/yr)	174,000	44,939	350,000	7,860,000
Cost per Watt ($/W)	2.41	7.50	3.00	1.97

A payback period can be calculated for each solar array as well. This payback period is essentially the time it takes for the array to "pay for itself" given the price of electricity. After it has generated enough electricity to offset its cost, it begins making money through generated electricity energy costs. At this point, it becomes economically viable to install an array, rather than installing one simply for the environmental benefits. An ideal payback period is as low as possible.

The payback period can be calculated in a number of different ways for our array, depending upon the price of electricity that is being used. APP can produce electricity at \$0.055/kWh [2], and is the cheapest electricity available to the Art and Design building. But sometimes, APP cannot provide adequate power to the campus, and so some must be purchased at a rate of \$0.063/kWh [2]. Finally, by assessing the energy usage and payments made by the Art and Design building directly, we calculated a cost per kWh of \$0.08 [15]. Although it is unclear whether this number is accurate, it can aid in determining a lower bound for payback period. Because the payback period depends on how quickly it can make up for the cost of the array through energy savings, the most costly electricity is for a given location, the faster it's payback period will be. Calculated payback periods (and ranges if multiple electricities costs available) can be found in Figure 7.This figure also includes the calculated payback period for an equivalent array composed of polycrystalline silicon (poly Si) on the Art and Design building, for the sake of benchmarking. All calculations took into account degradation of arrays, using data from NREL [16].

Figure 7:



From the payback periods, it is clear that our array is competitive and could be paid-back within the lifetime of the array (somewhere between 22.6-34.4 years). This is comparable to the MTD and Solar Farm arrays, and even better than an equivalent Poly Si array- the market leader material. The BIF has a large payback period because it was built in a period when solar technology was very much still budding and cost-prohibitive.

In addition to these local solar arrays, it was deemed crucial to understand what a conventional polycrystalline silicon array would cost if it were installed on the Art and Design building. A similar cost analysis was conducted, and similar to the final design cost analysis, the same quote was consulted. For a racked, polycrystalline array, issues arise with self shading since the panels are installed as a three dimensional structure rather than the flexible and flat mounted panels used in the final design. In order for a racked array to not create shade onto the next row of panels, spacing must be considered between the rows of the array. It was determined that 300 silicon panels could be installed on the Art and Design building with racking without shading issues. This number was determined by calculating the space necessary between each row of solar panels due to the panels being at a 45° angle and the solar altitude during the fall at noon. The resulting distance between each row was roughly 3 feet, 2 feet more than the spacing used in our design. Using this value, the following calculations were made. Fixed costs stayed exactly the same as the final design; however, the values that changed were the material costs and the installation costs. Since the quote was made for a 265W Astronergy panel with an individual microinverter system and an individual thermoformed racking system with a ballasted counterweight, it was determined the material costs could be scaled linearly to 300 panels. Similarly, using the estimate that rooftop installation time takes approximately 1.5 hours for each panel, the labor was also scaled linearly to 450 hours. Table 8 shows the costs of the comparable silicon array against our final design.

Table 8:

Items	Conventional Silicon Array	Final Design
Labor for Rooftop Installation	$41,144 (450 Hours)	$27,430 (300 Hours)
Auxiliary Electrical Work (116 Hours)	$10,606	$10,606
Crane	$1,500	$1,500
Approved Engineering Drawings	$5,000	$5,000
Materials	$159,808	$283,800
Total Cost	**$218,058**	**$328,334**
Dollar per Watt	**$2.74**	**$2.41**

The items in red are the fixed costs associated with installation.

While the final design system cost is over $100,000 more than the racked array, it is seen that the actual cost per watt of power is less. Further analysis yielded that the actual crossover point of when our final design yields a better dollar per watt value than a conventional system was at approximately 56 solar panels, as seen on the inset - Figure 8b. The curves seen in Figure 8a and 8b were created through calculations that were derived from the cost analysis of both the final design and the comparable polycrystalline silicon panel design. By fitting these two curves, a useful model was created regarding the cost per watt of a given array against the number of modules in the array itself. These curves were created using the following equation:

$$\text{Price per Watt} = \frac{Fixed\ Cost + (Price\ Per\ Module * Number\ of\ Modules)}{Rated\ Power\ per\ Module * Number\ of\ Modules}$$

Figure 8a:

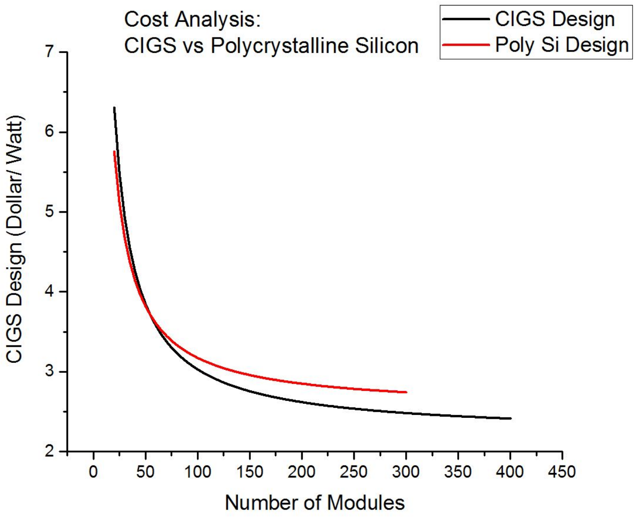
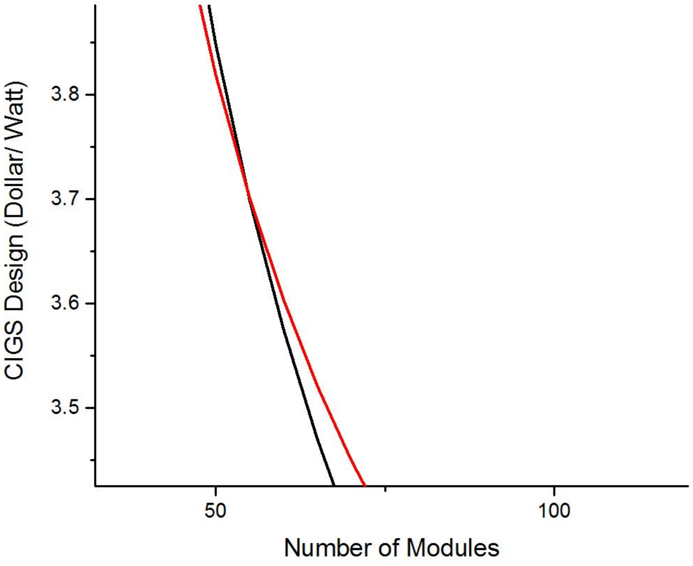
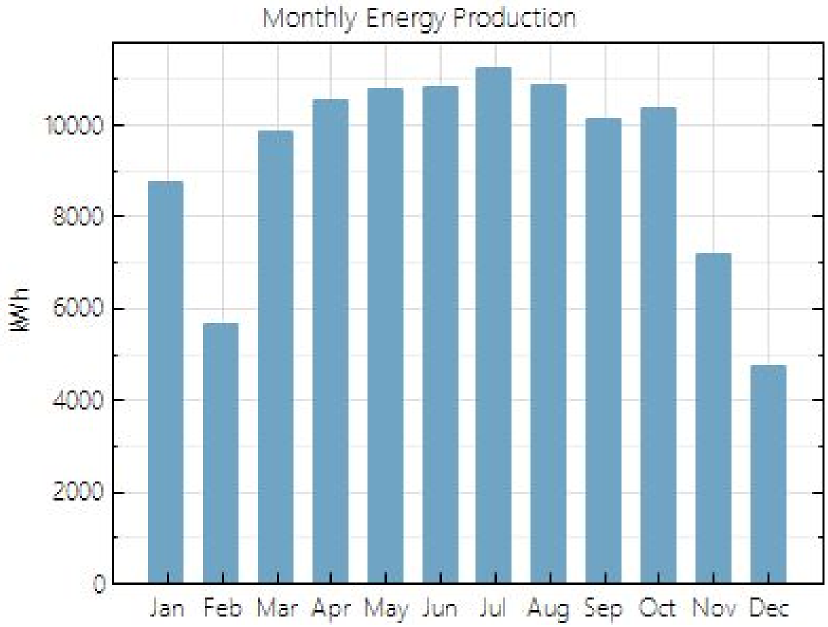


Figure 8b:



Our design can also be compared to a typical Poly Si array through a power output analysis using SAM. Estimating a typical Poly Si array would only be able to fit 300 panels in the same roof space due to racking and self shading, and factoring in a 45° tilt (roughly the most efficient for incident solar energy), Figure 9 was simulated in SAM.

Figure 9:



There are a few interesting things to note when comparing this Si energy production to our CIGS design energy output in Figure 9. First, there is much less of a dropoff in energy output in the winter months. This is attributed to their tilt. Rather than being roughly flat like our design, the 45° tilt allows for snow to come off the panels and stay less soiled. In addition during the winter months a tilted solar panel gathers more sunlight than a flat array and thus generates more power relatively during that time. However, due to efficiency and size constraints, our array still outputs significantly more power overall, and for a cheaper price. The total output of the Si array would be roughly 111 MWh per year compared to 174 MWh for our array. It would also suffer a longer payback period given lower efficiencies and higher degradation rates for Si versus CIGS. From nearly all benchmarking parameters (total cost, cost per watt, efficiency, cost and ease of installation, payback period, and even aesthetic pleasure), our array beats out an equivalent Si array. It also performs at or near the level of other local arrays of comparable size.

Another interesting thing to note about our design is that using CIGS solar panels flat on the roof actually has higher efficiency per area than using angled CIGS. The shading issues that cause a silicon array to only use 300 panels instead of 400 panels

V. Prototyping and Testing

Because this was purely a design project, no prototypes were made nor testing performed. Simulations through SAM could be considered prototyping of sorts, but other than that section is not applicable to our project. If this design were to be seriously considered for implementation in the future, it may be useful to prototype our design with a small handful of CIGS modules and microinverters. This could then confirm and justify if our design really performs as we predict, and if it is something that should really be encouraged.

Based on the current layout of the roof the simulated rooftop solar should appear as shown in Figure 10, resulting in the final rooftop looking like Figure 11. Removal of rooftop air conditioning units would allow for a few extra panels to be installed.

Figure 10:

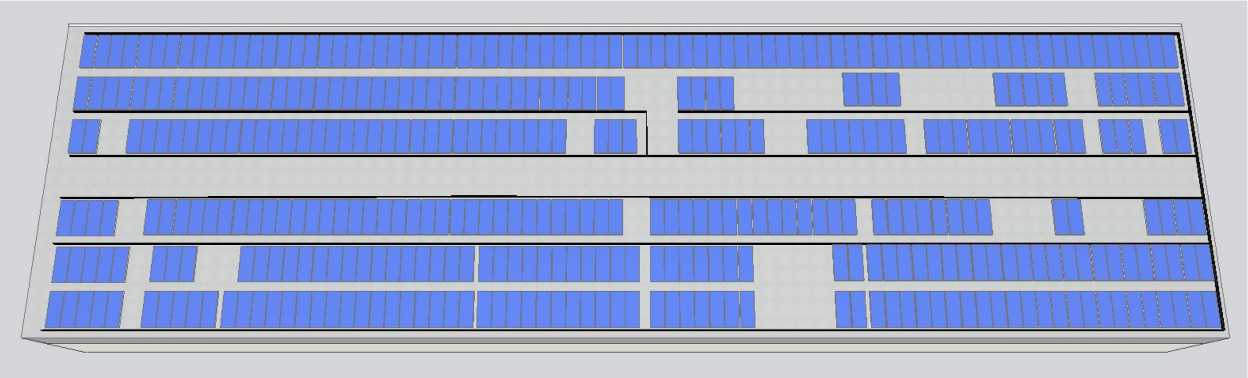
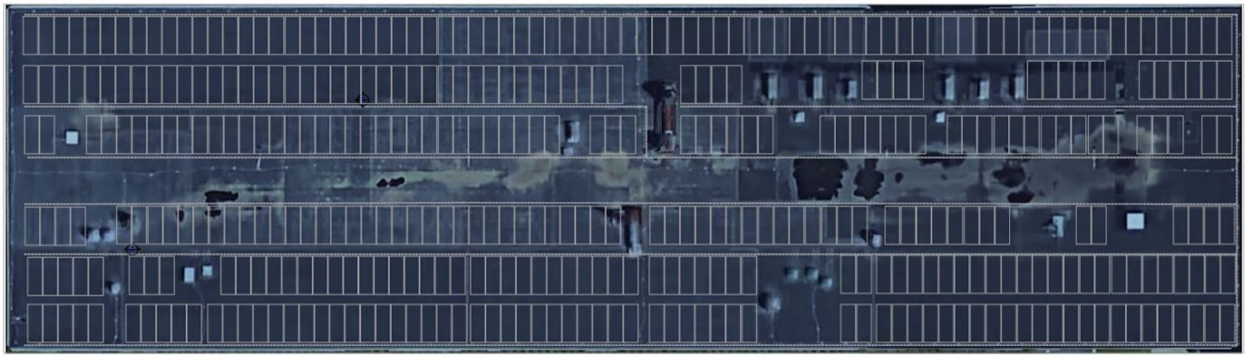


Figure 11:



VI. References

1. Illinois Climate Action Plan ("iCAP"), http://sustainability.illinois.edu/campus-sustainability/icap/
2. UIUC Utilities Master Plan, http://icap.sustainability.illinois.edu/project/utilities-master-plan-energy-production-and-distribution
3. Wunderground, "Champaign Weather History Jan 1st 2010 - May 11 2016", Math 11th, 2016
4. www.miasole.com, "Comparison of CIGS and Poly Si"; May 2nd, 2016
5. www.enphase.com,'Products- S280 Micro Inverter" May 10th, 2016
6. Industry Study Channel "p-n Junction" Web, May 9th, Image http://www.indiastudychannel.com/attachments/Resources/151970-9110.JPG
7. Shang, Jian. "Solar Cell – Lecture S15", University of Illinois Compass 2g, MSE308. May 9th; https://compass2g.illinois.edu/webapps/blackboard/execute/content/file?cmd=view&content_id=_1514672_1&course_id=_18670_1&framesetWrapped=true
8. U.S. Energy Information Administration - EIA - Independent Statistics and Analysis. (2014, October 08). Retrieved April 13, 2016, from https://www.eia.gov/tools/faqs/faq.cfm?id=9
9. Glesco Electric PV installation quote, privately accessed.
10. MiaSole Case Study - 3M Corperation. (2014). Retrieved March 12, 2016, from http://miasole.com/uploads/media/FLEXonTPO_3MCaseStudy_1_01.pdf

11. Astronergy, “Crystalline PV Module CHSM6610P (FR) Series”, http://www.astronergy.com/attch/product/20151019_VIOLIN_CHSM6610P(FR)4BB40mm.pdf
12. Tse, Ho Yee Natalie, “The Sustainability of the Photovoltaic Solar Panels on the Roof of Business Instructional Facility”, 4/28/2014. https://icap.sustainability.illinois.edu/files/projectupdate/2133/Solar%20on%20BIF.docx
13. MTD, “Solar”, Accessed 5/10/2016. https://www.cumtd.com/go-green/solar
14. UIUC Facilities and Services, “Solar Farm Project”. 12/15/2015. http://icap.sustainability.illinois.edu/files/project/175/solar-farm-project-fact-sheet_with-faqs_121515%282%29.pdf
15. UIUC Art and Design building power bills, privately accessed.
16. Jordan, D. C., & Kurtz, S. R. (2011). Photovoltaic Degradation Rates-an Analytical Review. Prog. Photovolt: Res. Appl. Progress in Photovoltaics: Research and Applications, 21(1), 12-29. doi:10.1002/pip.1182

VII. Appendix

Initial Timeline:

Tasks:

1. Identify building (F&S have desired locations/ waiting to hear back from them)
2. Map desired location of solar array on the roof of the building
3. Determine solar array based on price, efficiency, weight, et. cetera
    a. Talk to companies to help support projects and possibly donate
4. Determine mounting system for roof
    a. Want to minimize roof penetration
    b. Angle of solar cells and direction
    c. Cost
5. Determine energy delivery system (AC vs. DC, microinverter, et. cetera)
6. Benchmark other campus buildings (BIF, CUMTD, South Fields array, Re_home, Gable home)
7. Cost analysis of design
    a. break even time
    b. cost $/watt
    c. total cost
8. Energy analysis of design
    a. energy provided
    b. % of building's energy
9. Environmental impact of design
    a. amount of greenhouse gases saved
10. Obtain funding
11. Sales pitch - motivation
12. Solar array tilt and angle to maximize energy produced
13. Attempt to make small "demo" array
14. Build a mock-up final design (CAD, 3-d printing)
15. NREL's modeling software for location benchmarking

Things to be done in by task number:

Month	Finish Tasks	Start Tasks
February	1, 2, 5, and 6	3, 4, and 11
March	3, 4, 12, 15	7, 8, 9, 10, 13, 14, 15
April	7, 8, 9, 10, 11, 13, 14, 15	

February

1, 2, 5, 6, START 3, 4, 11

March

FINISH 3, 4, 12, 15

April

7-14

Assignments

1. GROUP
2. GROUP
3. Satoshi
4. Satoshi
5. Aneesh
6. Michael
7. Eli
8. Connor
9. Eli
10. GROUP
11. GROUP
12. Eli
13. GROUP
14. GROUP
15. Michael

Midterm Timeline
Determine

- Cost Analysis (April 15th) - Satoshi
  - Price per panel, racking, installation, inverters
  - Price per panel in terms of wattage
  - Pay back period
- Energy analysis (April 15th) - Connor
  - Simulation - SAM or PVWatts through NREL
- Environmental impact (April 15th) - Aneesh
  - Impact on carbon footprint (UIUC's goal of carbon neutrality)
- Mock up design - Size of array, racking system (April 1st) - Eli and Michael

End of Semester Timeline

Tasks:

Rough draft of final presentation by April 29th

Meet to complete final draft of presentation: May 4th

Deadline to add finishing touches for final presentation: May 5th

Finish rough draft of final report: May 10th

Meet to complete final report: May 12th

Finishing touches, turn in report, DONE: May 13th

Tasks were split up as follows:

Aneesh: Design Constraints, Motivation

Connor: Mission, Power Analysis & Benchmarking, Prototyping, Environmental Analysis

Eli: Final Design mockup, Inverter selection, CAD Figures

Michael: Materials background, materials selection, panel selection

Satoshi: Power and cost analysis, benchmarking, comparison to Si