Cornell University Solar Parking Canopy Proposal, 2020 (Ithaca, NY)

Engineering Report for Project in Environmental Engineering: Carbon Neutral Cornell

[https://www.bestructural.com/wp-content/uploads/2015/03/solar-canopy.jpg]

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I. Executive Summary

In 2013, Cornell University published its Climate Action Plan which serves as the University's most recent comprehensive plan to outline its carbon neutrality goals. It was updated to a "living document" in 2014 with the original 2013 plan to serve as the baseline report. The Climate Action Plan focuses on three pillars: **neutrality** (reduce Cornell's carbon emissions to net zero by 2035 or sooner), **innovation** (Create a living laboratory for low-impact behaviors, climate education, and research), and **leadership** (Lead by example on campus and exercise climate leadership beyond campus). This project aims to work in tandem with Cornell University's carbon neutrality goals as outlined in the 2013 Climate Action Plan Update.[1]

The team's goals for the project focused on a holistic process similar to the Climate Action Plan. Our objectives included the development of a(n):

1. Environmentally sustainable project which would lower campus carbon emissions.
2. Socially responsible project which captured the insight of the Cornell community.
3. Economically viable project which balanced initial construction costs with the future benefits of reduced energy costs.

The team first researched current universities with solar canopy technology to gain perspective on project dynamics and develop case studies on completed solar canopy projects. Then, in order to determine the feasibility of solar canopy technology on Cornell University's campus, the team engaged in three separate processes to study the potential social, economic, and environmental, social impacts of the project. First, a survey was conducted to collect data on Cornell community's perspectives on a large solar project for the campus and the possible social implications such as a rise in parking fees, aesthetics, and general support for solar energy. Second, a series of parking lots were chosen as potential sites for a solar canopy project and aimed to illustrate the various styles and designs that are available depending on the proposed site. Third, an economic analysis projected the potential cost to build, revenue generated, and carbon emissions that could be offset for each solar canopy design in the parking lot sites.

From the system analysis conducted on the designated lots of this project as well as their designs, we note that Design 1 for Lot #3055 has the least expensive system cost of $1,157,760 with a payback period of 33 years, a system output of 448,105 kWh/year, and an estimated emissions savings of 51.53 MTCO2/year. This design has the smallest installed area of 2,235 m^2 . In comparison, Design 1 for Lot #4014 has the most expensive system cost of $6,914,400 with a payback period of 22 years, a system output of 4,014,270 kWh/year, and an estimated emissions

[1] C., & P. (2013). *2013 Climate Action Plan Update & Roadmap 2014-2015* (Rep.). Retrieved 2020, from https://sustainablecampus.cornell.edu/sites/default/files/2019-01/Cornell%20University%20CAP%20Roadmap%20-%202013_0.pdf

savings of 461.64 MTCO2/year. This design has the largest installed area of 20,023 m^2 . Therefore we conclude that while a larger lot may correspond to a higher system price, it can also be more economically feasible as a long-term investment with its large capacity and shorter payback period. Likewise, a larger design would result in higher CO2 emission savings and push the campus closer to its carbon neutrality goal.

In addition to our system analyses, we have included several possible scenarios for the continuation of future solar canopy projects to be implemented on Cornell's campus. These illustrate the diverse factors that can affect both the short term and long term sustainability of the project. These examples are intended to be a part of the University's pre-planning process to implement a project of this scale on campus. We hope that our analysis provides insight to further research on the potential for a future campus solar panel project.

II. Team Member Backgrounds

Francis Vanek is the faculty adviser of this project. He is from Ithaca, NY, and has an undergraduate engineering degree from Cornell University (1991) and graduate degree from the University of Pennsylvania (1998). His role is to advise the team on their research on supporting a carbon-neutral campus, and he expects to continue working with graduate student teams on this project in future semesters. Outside of work, his interests include bicycling, yoga, and piano.

Cynthia Chu is from Long Island, NY. She received her Bachelor's of Science in Environmental Engineering from Cornell University in May 2020, and is currently pursuing her Master of Engineering degree in Environmental Engineering at Cornell University. She works at Cornell's Campus Sustainability Office and enjoys camping, canoeing, and reading in her free time.

Jiwon is from Santa Clarita, CA. She graduated with a Bachelor's in Environmental Engineering and a minor in Climate Change from Cornell University in May 2020. She is now finishing her M.Eng. degree in Env. Eng. with a focus in sustainable energy systems and will be graduating in December 2020. She's passionate about the environment and is interested in sustainable buildings, specifically reducing energy consumption in the built environment. When she's not working, she can be found trying out a new recipe from Bon Appetit or playing Catan with her friends.

Lynn Li is from Pittsburgh, PA. She graduated with a Bachelor's of Science in Environmental Engineering and a minor in Creative Writing from Cornell University where she is currently pursuing a M.Eng. also in Environmental Engineering with a focus in water resources. Lynn will graduate in December 2020. Outside of work, she is interested in photography, traveling, and hiking.

Jenna DeRario is from Poughkeepsie, NY. She graduated with a Bachelor's of Science in Environmental Studies from the State University of New York at Buffalo in 2015. She is currently pursuing a Master of Regional Planning degree with a concentration in Land Use and Environmental Planning. She enjoys hiking and playing sports in her free time.

III. Project Purpose

This project aims to determine possible solar canopy locations on Cornell University's campus through a participatory survey, an informed design process and an economic analysis study. The main objective of these solar canopies is to generate renewable energy that can reduce greenhouse gas emissions for the University. Additional benefits include lower utility costs, vehicle shading, and the public display of sustainable practices. The structures take no additional space but simply use the parking lots for multiple uses. A solar carport can help reduce the "heat island" effect of parking lots and contribute to a cooler community, and by providing protection from the elements, it can help enhance vehicle lifespan.[2] These benefits would complement Cornell's 2013 Climate Action Plan Update as they would lower the campus's carbon footprint, display an innovative design, and showcase Cornell as a leader in climate change mitigation and adaptation.

Figure 1: Cornell's 2013 Climate Change Update[3]

[2] *University of Redlands Solar Feasibility Study* (pp.20, Rep.). (2012). Redlands, CA: University of Redlands. doi:https://sites.redlands.edu/contentassets/8215658cdb9a4f9bb43a8fa49223bea7/uor-reports--initiatives/uofr-solar-feasibility-study-2012.pdf

[3] Climate Action Plan. (n.d.). Retrieved December 16, 2020, from https://sustainablecampus.cornell.edu/our-leadership/cap

IV. Site Description

As mentioned in the executive summary, the designs developed in this project are to be implemented on Cornell University's main campus in Ithaca, NY. After using Cornell's ArcGIS map of parking locations, we have chosen three distinct parking lots that we found to be suitable and ideal for our solar canopy project. The locations aim to highlight the diversity of designs, costs, and scale of solar canopies.

The three lots we have chosen are:

1) Lot # 3055 (along Tower Road next to the Soccer Fields)
2) Lot # 4014 (Cornell Vet School parking lot)
3) Lot # 4015 (Teaching and Research Barn parking lot)

The GIS images of the three lots along with an explanation of why each plot was chosen are shown below.

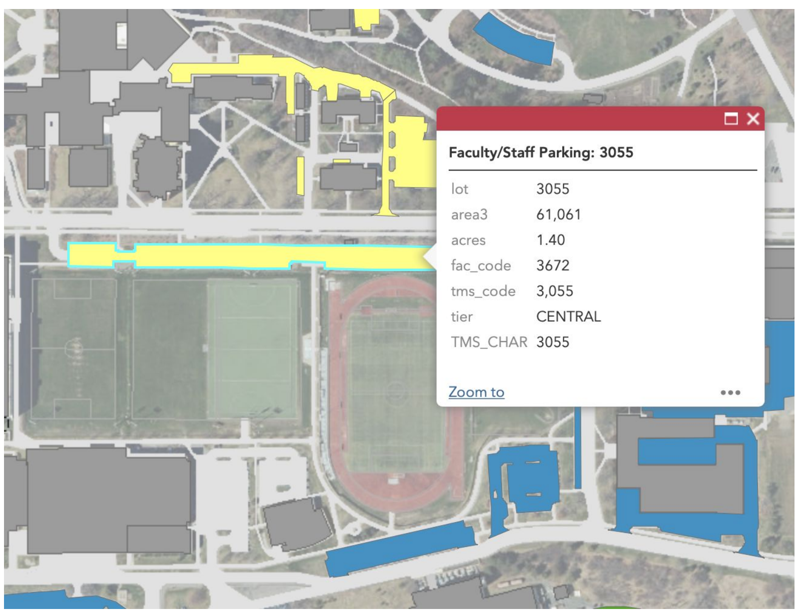

Figure 2: GIS Map Image of Lot #3055

Lot #3055 stood out to us from the get-go because of its unique strip shape that makes it ideal for a singular row of solar panels. In addition, we have chosen this lot because it is one of the biggest lots located on central campus. Its total surface area amounts to around 5666 m^2 which makes it the smallest lot out of the three we have chosen. The benefit of choosing a lot located on central campus is that students would be able to see the panels on a regular basis and so it has the potential to raise solar awareness and to normalize solar panels on campus.

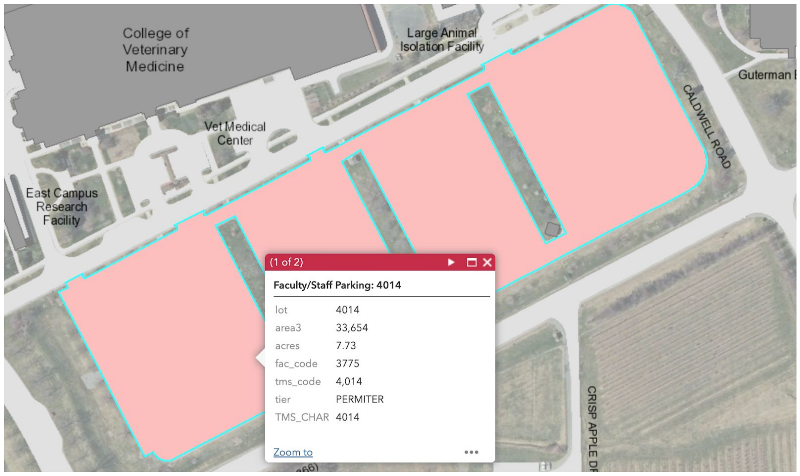

Figure 3: GIS Map Image of Lot #4014

Lot #4014 is the Cornell Vet School parking lot. This lot was primarily chosen for its large surface area which makes it optimal for a solar project. The total area of this lot is around 20023 m^2 . In addition, it has a rectangular shape unlike the previous lot which allows for a different type of solar canopy design. In general, we wanted to pick three common but distinct parking lot shapes so that the designs we create may be more easily implemented on a variety of other lots across Campus that may have a similar shape.

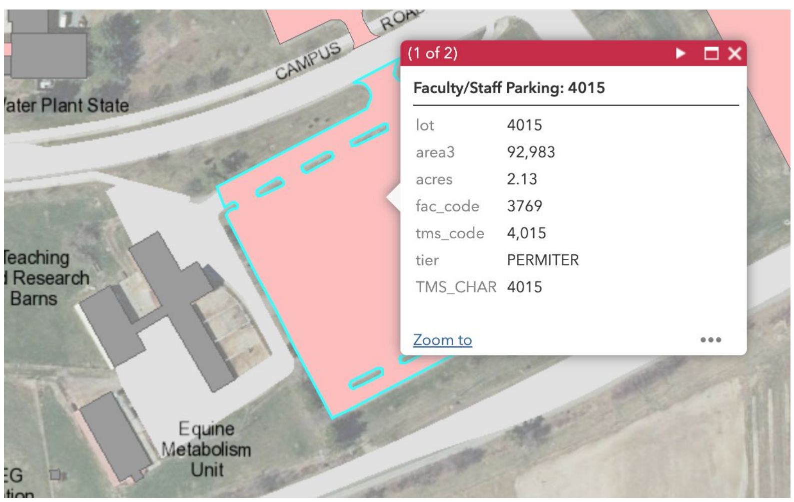

Figure 4: GIS Map Image of Lot #4015

Lastly, we have lot #4015 which is a faculty parking lot next to the teaching and research barns. Again, this lot was chosen for its large surface area of around 7018 m^2 . The physical shape of this lot is quite similar to that of lot #4014; however, it is much more square than rectangular.

VI. Case Studies

Before we started our analysis, we researched examples of solar panel projects at universities around the United States. Our case studies exhibit the array of funding and design opportunities that are available for solar technology on university campuses.

Duke University

In 2018, Duke University began the development of its on-campus solar panel project. Installed by a private company known as Green State Power, the 2,554 panels were installed on top of a parking garage. The project produces 1.3 million kWh of electricity annually to power the garage and other campus buildings and eliminates 430 metric tons of carbon per year from Duke's footprint. In addition, the structure also captures rainwater which is used in the campus irrigation system. The project, costing $2.3 million, had one major flaw in the original design. The developers failed to account for the possibility of snow as it is not a common occurrence in the region. However, after a big snow storm, snow guards were installed on the panels.[4]

Figure 5: Solar Parking Canopy at Duke University

[4] Green State Power completes Duke University's Solar Parking Canopy. (2019, March 04). Retrieved December 15, 2020, from https://www.greenstatepower.com/green-state-power-completes-duke-universitys-solar-parking-canopy/

University of Massachusetts Amherst

In 2017, the University of Massachusetts Amherst partnered with Sol Systems and ConEdison Solutions to install 15,000 photovoltaic panels across campus. The resulting project, which cost $16 million to develop, provides 5.5 megawatts of clean electrical power. Over the next 20 years, the project will cut the university's electric bills by $6.2 million and will reduce the equivalent of 31,000 non-metric tons of carbon dioxide. The project will produce 5.9 million kWh of renewable energy annually. The University currently buys the electricity from Sol Systems and ConEdison Solutions through a power purchasing agreement.[5]

Figure 6: Solar Parking Canopy at University of Massachusetts Amherst

University of Maryland

In 2017, the University of Maryland, in partnership with WGL Energy and Maryland Energy Administration, installed solar canopies on top of three parking garages on campus. More than 7000 solar panels were installed, and the solar power generated will amount to over 2 MW of renewable energy. The resulting solar canopies would provide a total of 3,941,000 kWh of renewable energy annually. The project was a collaboration between UMD's Department of Engineering & Energy in Facilities Management and the Department of Transportation Services. The solar canopies were funded through a $250,000 grant from Maryland Energy Administration, which Facilities Management matched.[6]

[5] S. (n.d.). 15,000+ Solar Panels: 5 Buildings & 2 Parking Lots. Retrieved December 15, 2020, from https://www.umass.edu/sustainability/climate-change-energy/solar/15000-solar-panels-5-buildings-2-parking-lots

[6] U. (n.d.). UMD increases renewable energy use with installation of solar panel canopies. Retrieved December 15, 2020, from https://sustainability.umd.edu/connect/umd-increases-renewable-energy-use-installation-solar-panel-canopies

Figure 7: Solar Parking Canopy at University of Maryland

University of Hawaii Manoa

In 2018, the University of Hawaii Manoa launched a solar canopy project on the main campus parking structure. The panels will produce 2 MW electricity each day, and are anticipated to save $2-$3 Million depending on the university's future energy costs. The solar canopy project is a part of a Power Purchase Agreement, where the university does not have to pay until it receives 1 kWh after installation of the solar canopy. Although the solar canopy may be an inconvenience for visitor parking, it is a small price to pay for long-term energy savings. UH Manoa currently has a goal of net zero by 2035.[7]

[7] Tam, N. (2019, January 5). Solar canopy being installed at UH Manoa's main campus parking structure might make it harder to find parking. *KITV4 Island News*. Retrieved 2020, from https://www.kitv.com/story/39738752/solar-canopy-being-installed-at-uh-manoas-main-campus-parking-structure-might-make-it-harder-to-find-parking

Figure 8: Solar Parking Canopy at University of Hawaii Manoa

University of Redlands

This 2012 study assessed the technical and financial feasibility of a solar photovoltaic installation on the University of Redlands campus. The study estimated the pricing of solar canopy parking structures would stand at $3.50 per watt, but fortunately, the return on investment for property owners can be in the range of 10 to 15 percent. Parking lot locations were evaluated for their size, solar potential, and distance from electrical tie-in points (to reduce transmission costs). The parking canopies were found to be the most expensive on a per watt basis due to the higher cost of materials and installation. However, the study cites the duality of the structures from their use of space as well as the appeal to incoming students as a counterpoint.[8]

The following table summarizes the characteristics of the solar canopy projects that we have researched.

[8] *University of Redlands Solar Feasibility Study* (pp. 1-36, Rep.). (2012). Redlands, CA: University of Redlands. doi:https://sites.redlands.edu/contentassets/8215658cdb9a4f9bb43a8fa49223bea7/uor-reports--initiatives/uofr-solar-feasibility-study-2012.pdf

Table 1. Summary of Case Studies

Institution	**City & State**	**Year Introduced**	**kWh per year**
Duke University	Durham, NC	2018	1.3 million kWh
University of Massachusetts Amherst	Amherst, MA	2017	5.9 million kWh
University of Maryland	College Park, MD	2017	3.941 million kWh
University of Hawaii Manoa	Honolulu, HI	2018	730,000 kWh
University of Redlands	Redlands, CA	2012	646,681 kWh

VIII. Survey

Survey Methodology

The goal of the team's survey was to gain insight into the opinions of students, faculty and alumni on the potential for a solar canopy on campus. Each team member first conducted research on previous solar surveys and case studies to develop the questions for the survey. This research informed the content and format of the final set of questions for the survey. The questions were then uploaded and formatted to Qualtrics. The final version of the survey included 12 questions pertaining to solar panel knowledge, ranking factors of a potential project from important to least important, current parking practices/ permits and the effects of a parking fee increase due to implementation of a solar canopy project.

Question 1: *Intro paragraph explaining the survey to participants*

Question 2: *What is your University affiliation?*

Question 3: *On a scale of 1-5, how much do you already know about solar energy?*

Question 4: *How would you feel about having a large solar array on campus?*

Question 5: *Rank these factors as we consider a Cornell solar canopy project from most important (1) to least important (4).*

Question 6: *Rank these factors that would prevent you from supporting the solar canopy project on campus most important (1) to least important (4).*

Question 7: *If you park on campus, which kind of parking permit do you have?*

Question 8: *In which parking permit tier do you typically park?*

Question 9: *If you park on campus, which type of parking permit do you have?*

Question 10: *Which residential area is your assigned permit area?*

Question 11: *What kind of commuter permit do you have?*

Question 12: *If the presence of solar canopies over Cornell's parking lots would require parking fees to increase, would you be willing to pay more for your parking spot in exchange for shade/protection of your car and to help make Cornell Carbon Neutral?*

Question 13: *Do you have any other thoughts on the potential solar canopy project that you would like to share with us?*

Figure 9: Solar Canopy Survey Questions

The online survey link was shared to various members of the Cornell community including but not limited to current students in the College of Engineering and the City & Regional Planning Department. Other participants of the survey include Cornell alumni and faculty. The team did not intend to conduct a statistically sound survey and recognizes that the results come from a small subset of Cornell's student body. However, the survey served to capture perspectives on the social implications of this type of solar project. In total, the survey received 62 responses.

Graduate and undergraduate students made up the majority of the survey participants as seen in the table below.

Table 2: University Affiliation of Survey Participants

Graduate Student	26
Undergraduate Student	27
Alumni	6
Staff/Faculty	3
Total	62

Survey Results

The following survey results most informed our decision making objectives throughout the design process. These survey results determined that there was an interest for solar on campus, participants were mostly interested in how much carbon output the project will offset, and participants did not have a concise view on whether they would be willing to pay more for parking fees due to a large solar canopy project. The other survey results from the rest of the questions did not contain conclusive results and therefore were not included in this analysis. We found that most of the students skipped the questions pertaining to their parking permit and for this reason we have decided to exclude them from our final analysis. These questions were intended to be used to determine a potential location for a solar canopy. As we will talk about later in the design process, we instead picked potential locations through the analysis of a current GIS map of campus parking lots.

When asked *"**Question 4:** How would you feel about having a larger solar array on campus?"*, the majority of participants ranked their response as "very positively" as seen in the results of Figure X.

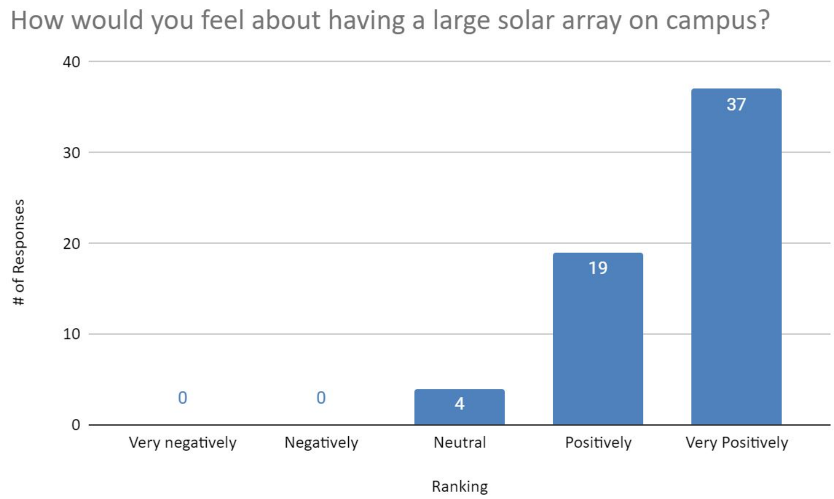

Figure 10: Results from Survey ***Question 4***

In response to *"**Question 5:** Rank these factors as we consider a Cornell solar canopy project from most important (1) to least important (4)"* overall the participants ranked the factors in the following order displaying their emphasis on support for the overall carbon emissions output and power generation of the system.

1. ***(Most important)*** *How much carbon output the project will offset.*
2. *How much power the system will produce (kW).*
3. *How much it will affect the price of parking on campus.*
4. ***(Least important)*** *How the project affects the aesthetics of the University's campus.*

In response to "***Question 12:*** *If the presence of solar canopies over Cornell's parking lots would require parking fees to increase, would you be willing to pay more for your parking spot in exchange for shade/protection of your car and to help make Cornell Carbon Neutral?"* the majority of participants ranked their response as "Willing" as seen in Figure X below. However, 13 participants responded with "Neutral" and 12 with "Could be convinced" displaying a level of uncertainty into whether they would truly be willing to pay for parking fees due to a solar canopy project.

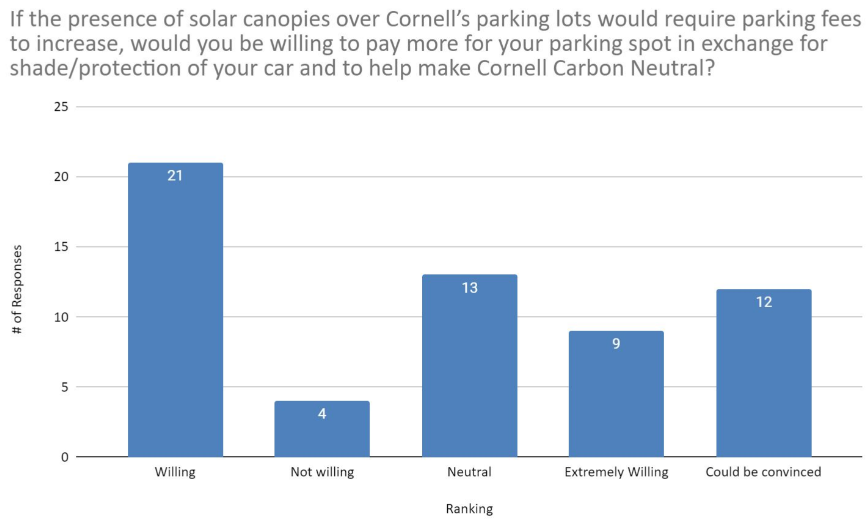

Figure 11: Results from Survey ***Question 12***

In response to ***Question 13:*** *Do you have any other thoughts on the potential solar canopy project that you would like to share with us?,* participants shared key critical comments on their thoughts for a solar canopy project. Some of these comments include:

- "Parking is already very expensive. I believe adding solar capability is better on buildings rather than on parking lots."
- "Some examples of metric would be nice to imagine more clearly, i.e. actual number of increase in parking fee."
- "How would Ithaca's winters affect solar canopy?"
- "Solar canopies should help LOWER parking fees, which are already onerous. Increasing parking fees is entirely unacceptable."
- "I think that anything an institution can do to minimize its reliance on fossils fuels is a benefit. I would hope that the solar array is designed to last a long time to minimize impact due to material cost and the waste of a system replacement."
- "I think they would be an aesthetic asset!"

The conclusive results of this survey inferred that the participants ranked the amount of carbon output that would be offset and how much power the system would produce over the aesthetics of the structure. There were mixed results from the participants about their willingness to pay extra for parking if the solar canopy structure was built. Overall, the participants answered that they felt very positively when asked how they would feel about having a solar array on campus. These results provided an emphasis for the design process in which it focused on the amount of solar energy generated and the cost of each design.

IX. Design Components

Solar Panel: Jinko Eagle 1500V 72 JKM 335PP-72-V

In order to be able to conduct a financial and system's output analysis, we needed to pick a specific solar panel to use for this project. We wanted to pick a popular standard industry panel which would give us values comparable to other solar panel models that a contractor may use. The panel model we've chosen is the Jinko Eagle 1500V 72 JKM335PP-72-V from JinkoSolar, one of the largest PV manufacturers. The chosen panel model is pictured below in Figure X.

Figure 12: Jinko Eagle 1500V 72 JKM335PP-72-V

Below is a table of the panel's properties that we've used in our analysis. The nameplate power rating of this panel was taken as constant; variations on performance due to ambient temperature differences and lifetime degradation were neglected in our analysis.

Table 3: Jinko Eagle 1500V 72 JKM335PP-72-V Stats

Variable	Value	Unit
Rated Power	335	W
Rated Power per Cell	4.65	W
Efficiency	17.26%	
Output Warranty Term	25	year
Panel Length	1956.0	mm
Panel Width	992.0	mm

Panel Depth	40.0	mm
Cell Size	156 x 156	mm
Cell Count	72	

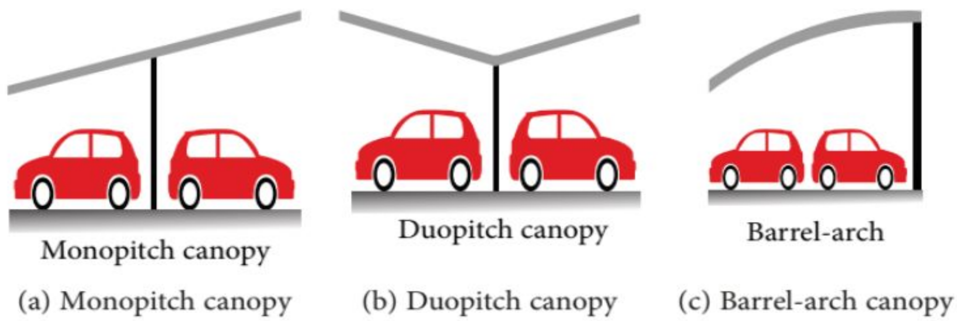

Figure 13: Three Basic Solar Canopy Types[9]

In our preliminary design research, we looked at three basic solar canopy types, as shown in Figure X. The monopitch canopy design has a single slope angle, with a tilt angle that typically ranges from 5° to 10°. This tilt angle is optimal both visually and for shade to cars. The tilt angle impacts solar photovoltaic generation, and the PV generation at the monopitch roof canopy angle is maximum as a tilt angle of 10°. The duopitch canopy, as shown in (b) of Figure X, comprises two roofs at the north and south end, creating a valley in between where the rows face each other.

Analysis of monthly PV generation at tilt angles of 5° and 10° show that the PV generation of duopitch roof canopies is higher at a 5° tilt angle. The barrel-arch canopy is more complex, with a curved shape with different tilt angles at each point of the roof. Comparison between the three canopy types shows that the barrel-arch canopy yielded 90% with respect to the monopitch canopy. Duopitch yielded 93% with respect to monopitch.[10]

[9] Sourced from https://www.hindawi.com/journals/ijp/2019/6372503/
[10] Umer, F., Aslam, M. S., Rabbani, M. S., Hanif, M. J., Naeem, N., & Abbas, M. T. (2019). Design and optimization of solar carport canopies for maximum power generation and efficiency at Bahawalpur. *International Journal of Photoenergy*, *2019*.

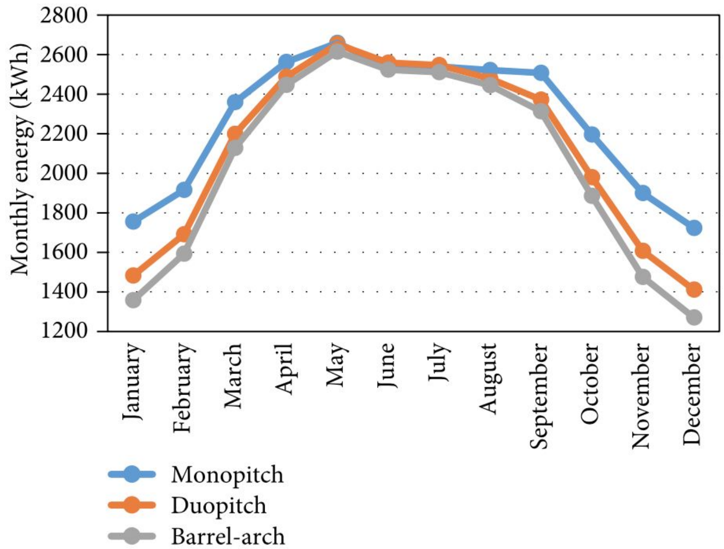

Figure 14: Comparison of PV Generation of Monopitch, Duopitch, and Barrel-Arch Canopies[11]

[11]Umer, F., Aslam, M. S., Rabbani, M. S., Hanif, M. J., Naeem, N., & Abbas, M. T. (2019). Design and optimization of solar carport canopies for maximum power generation and efficiency at Bahawalpur. *International Journal of Photoenergy*, *2019*.

XI. Final Designs

In this study, a series of calculations were carried out for sizing of canopy covers, solar energy potential of a car parking lot at a proposed site, and detailed economic analysis to project cost and revenue.

These solar projects follow various designs and styles and can be seen as the traditional row after row of raised rectangular strips (Figure X) or column after column of single pole-mounted panels, resembling a grove of trees. The canopies themselves also can take on different forms as depicted in Figure X.

Figure 15: Rows of Raised Rectangular Strips of Solar Panels

The lots chosen for the design process were detailed in the Site Description of this report. However, to reiterate, the three lots chosen were Lot # 3055 (along Tower Road next to the Soccer Fields), Lot # 4014 (Cornell Vet School parking lot), and Lot # 4015 (Faculty parking lot next to the Teaching and Research Barns).

To accurately estimate the dimensions of each lot, we used Pictometry and Google Maps, which provide three-dimensional aerial photographs to view high-resolution images. This feature was used to estimate both the size of the lots and the individual parking spaces. An example of this method can be seen in Figure 16. The rest of these pictometry figures can be found in Appendix B.

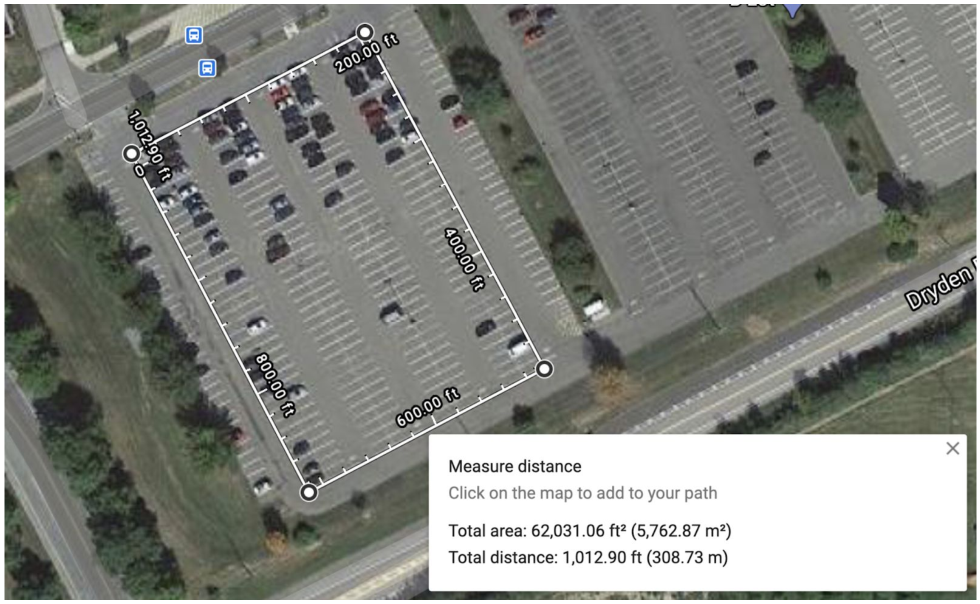

Figure 16: Pictometry Estimation of Larger Rectangular Lot #4014

Table 4: Areas of All 3 Chosen Lots

Parking Lot Locations	**Area Estimation (m^2)**
Lot #3055	5,666
Lot #4014	20,023
Lot #4015	7018

Lot #3055 Design 1

For this first location, we decided to test two different designs to best determine the most feasible option. The first would be one long strip of monopitch panels slanted south against the soccer fields to maximize solar intake, as shown in Figure X. This is one of the smaller proposals, with an area of $2235\ m^2$ and estimated to produce 448,105 kWh of clean electricity per year.

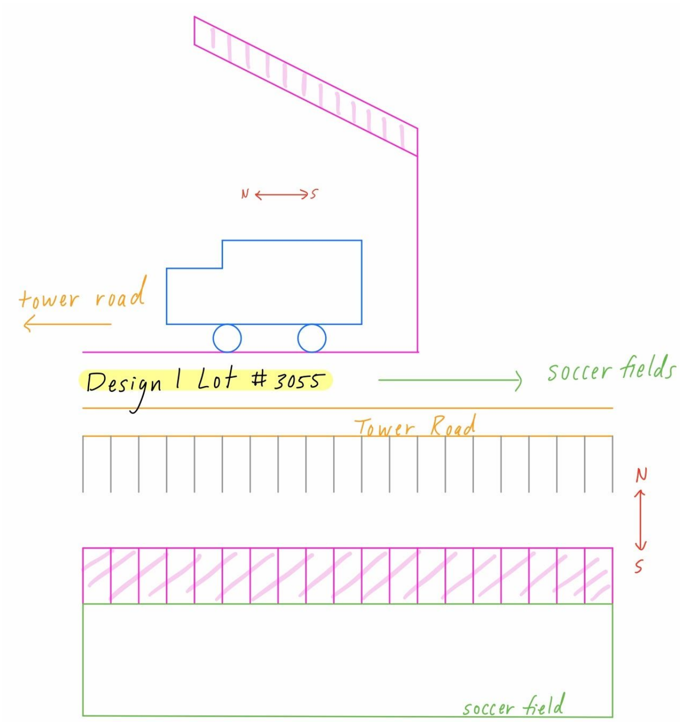

Figure 17: Design 1 for Lot #3055

Lot #3055 Design 2

The second design involves one large monopitch canopy over the entire lot angled south toward the soccer field once again. This canopy spans $5666\ m^2$ and has an annual output 1,136,209 kWh.

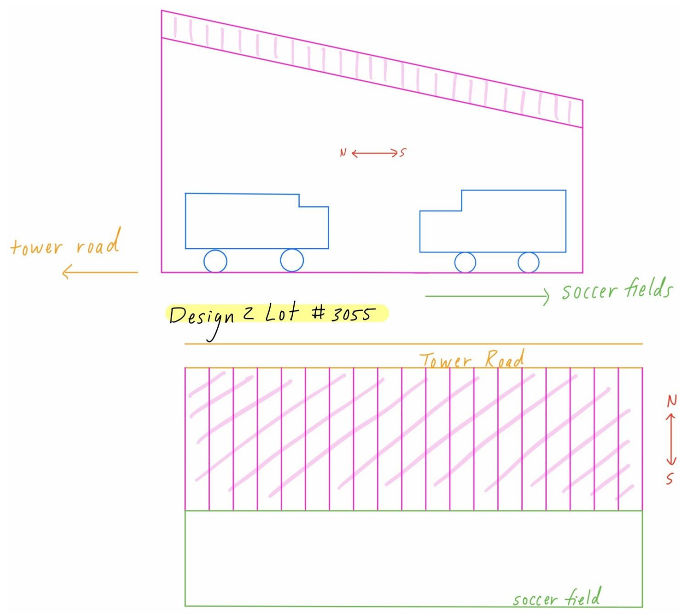

Figure 18: Design 2 for Lot #3055

Lot #4014 Design 1

For this location, we decided to test two different designs to best determine the most feasible option. The first would be four large rectangular monopitch canopies slanted south to maximize solar intake, as shown in Figure X. Each of these four monopitch canopies would cover the entire allotted parking area. This is our largest proposal, with a total area of 20023 m^2 and system output of 4,014,270 kWh per year.

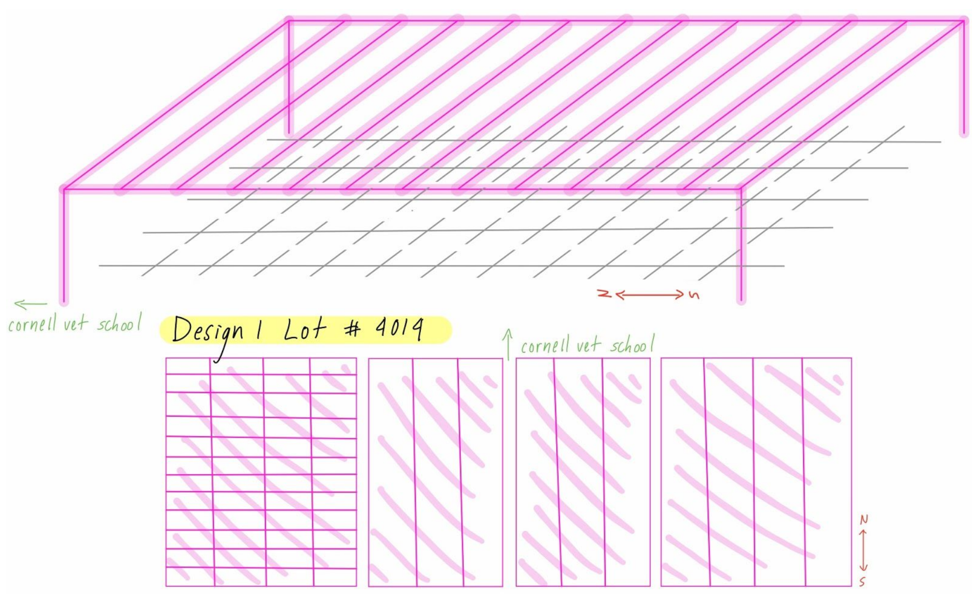

Figure 19: Design 1 for Lot #4014

Lot #4014 Design 2

The second design for this location was alternating strips of panels also facing south to maximize solar intake. With a total of eight panel strips, the total area would be 8071 m^2 and is estimated to produce 1,618,155 kWh annually.

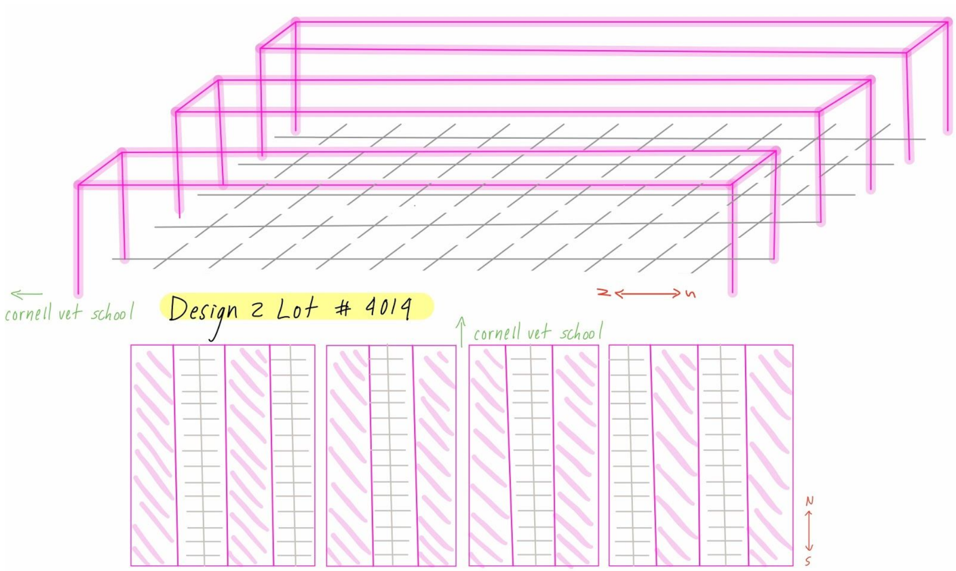

Figure 20: Design 2 for Lot #4014

To clarify, although there is no panel tilt represented in the design sketches for Lot #4014, this is not the case for the actual design. Having no tilt would severely negatively affect the energy output of this PV system. In our calculations, we will assume a 20-degree tilt South which again is variable and is ultimately at the discretion of a contractor.

Lot #4015 Design 1

Since we had already designed a large monopitch system for the previous rectangular lot (Lot #4014), we decided to go for a barrel design on Lot #4015. Again, like the last lot, the first design for this location is a large overarching barrel canopy which will cover the entire parking lot. This would result in a total panel area of 7,018 m^2 and output approximately 1,406,939 kWh annually.

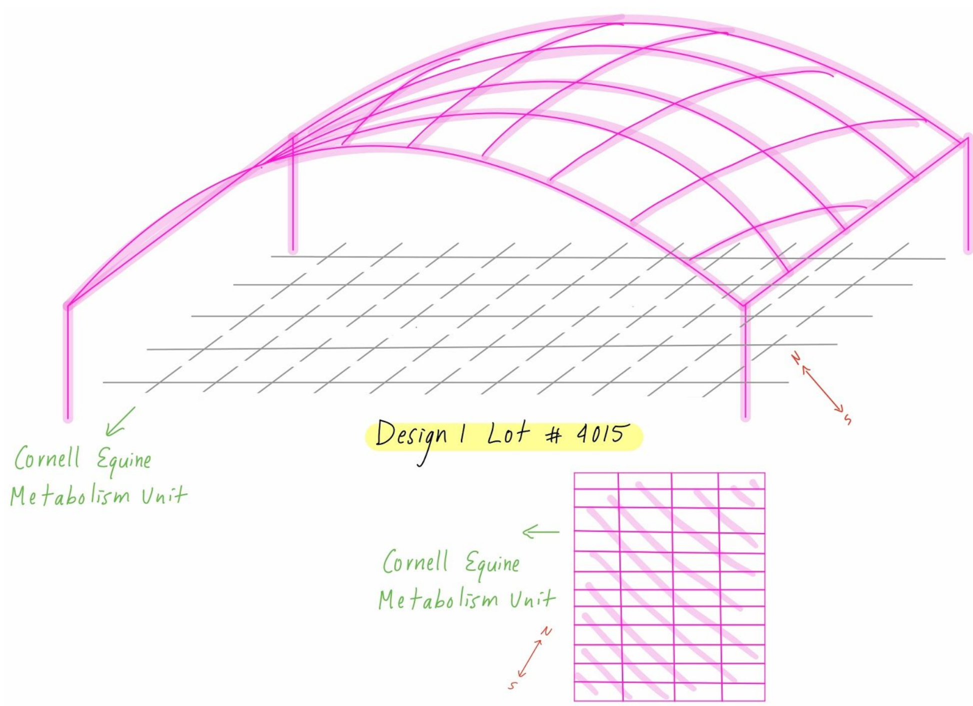

Figure 21: Design 1 for Lot #4015

Lot #4015 Design 2

Lastly, the second design for this location consists of alternating strips of barrel panels across the parking lot. With a total of 2 strips, the total panel area would be 2,456 m^2 and the system output is calculated to be about 492,448 kWh per year.

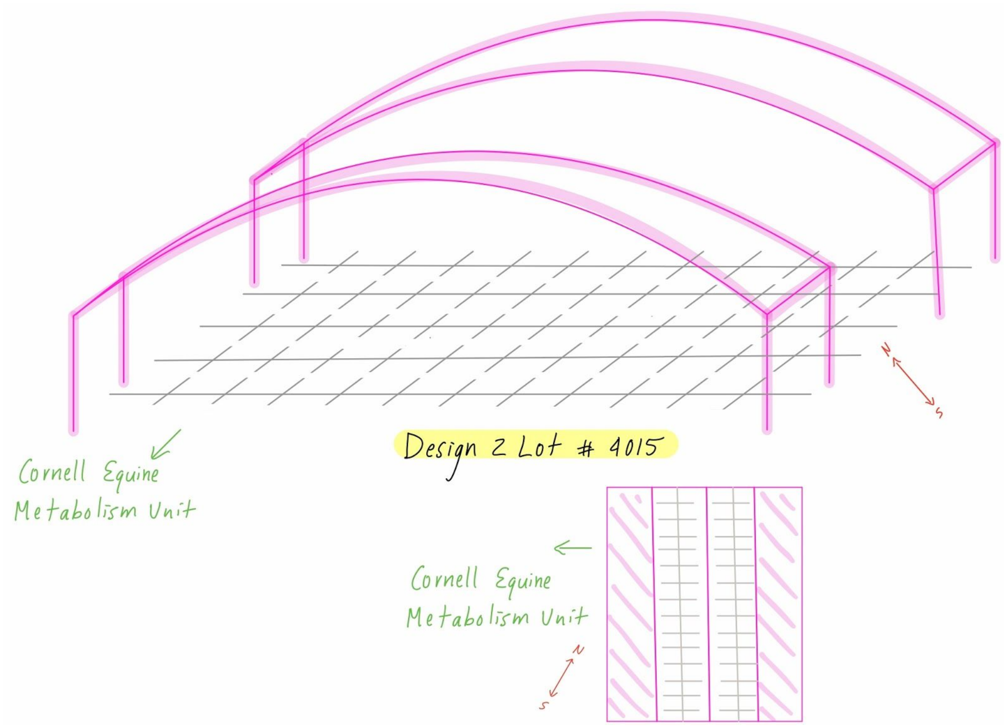

Figure 22: Design 2 for Lot #4015

XIII. Technical Analysis

To adequately analyze the economic and environmental benefits of the six proposed designs, the following calculations were performed for each one. With the panel specifications of the earlier mentioned Jinko Eagle panels, we were able to estimate the DC system size (kW).

$$\#\ of\ Panels\ =\ \frac{installed\ area\ of\ lot}{area\ of\ a\ PV\ panel}$$

$$System\ Size\ (kW)\ =\ \#\ of\ panels\ *\ panel\ output\ (W)$$

Using the well-trusted [PVWatts Calculator]() and assuming the subsequent details in Figure X, we calculated the annual system output (kWh).

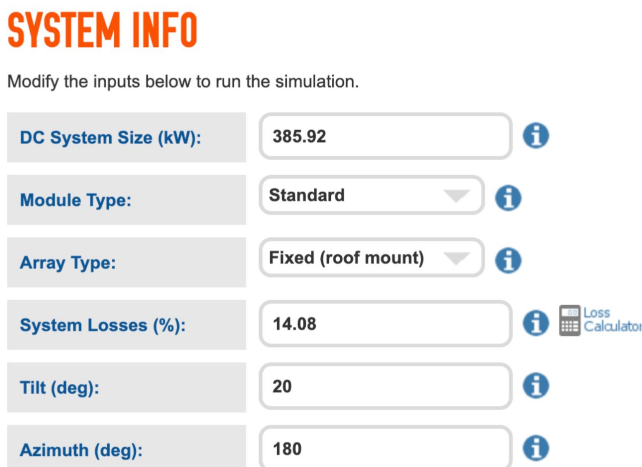

Figure 23. Example of Inputs for PVWatts

Next, we determined the simple payback period of installing such a system using the equation below:

$$Simple\ Payback\ Years\ =\ \frac{Net\ Cost}{Annual\ System\ Output\ *\ Production\ Value}\ .$$

The net cost here refers to the total price of the system based on the sliding scale in Figure X, which roughly estimates the average cost of a solar system per watt based on the size of the system.

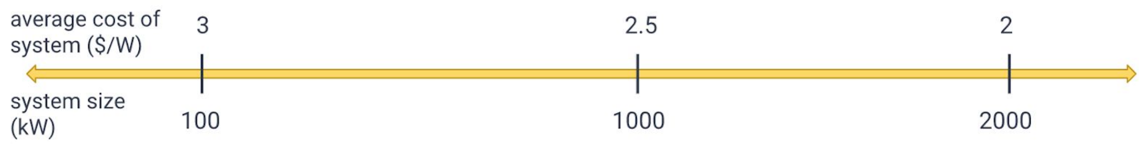

Figure 24. Sliding Scale of Average Cost of Solar Canopy System Based on Its Size

The production value, or the LCOE per kWh, was determined to be \$0.08/kWh in 2019 for Cornell University. Lastly, the calculated simple payback period value was compared to the average life of a system of solar panels of 25 years, but more on that later.

To further evaluate the system, we then found the annual emission savings of each proposed design using the simple equation below and an emission factor of 115 kgCO_2/MWh for Cornell:

$$Emission\ Reductions\ (MTCO_2)\ =\ Emission\ Factor\ *\ Annual\ System\ Output\ .$$

And assuming a carbon tax of \$100 per metric ton of CO_2 in the future, these emission savings would translate to financial savings as well.

As reference, below is what the analysis looks like for Design 1 of Lot # 3055.

$$\#\ of\ Panels\ =\ \frac{2{,}235\ m^2}{1.9404\ m^2} = 1152\ panels$$

$$System\ Size\ (kW)\ = 1152\ * 335\ W = 386\ kW$$

$$PV\ Watts\ \text{->}\ 448,105\ kWh/year$$

$$Simple\ Payback\ Years\ =\ \frac{(386\ kW) * (\$3/W)}{(448{,}105\ kWh/year) * (\$0.08/kWh)} = 33\ years$$

$$Emission\ Reductions =\ 115\ kgCO_2/MWh * 448,105\ kWh/year\ *\ 0.001\ MT/kg = 51.53\ MTCO_2$$

$$Carbon\ Tax\ =\ \$100\ /\ MTCO_2\ * 51.53\ MT\ =\ \$5,153/year$$

The other 5 designs were evaluated similarly.

XV. Results and Discussion

The calculations detailed above resulted in the following summary table.

Table 5. Summary Table of Possible Scenarios

Parking Lot Locations	Installed Area (m2)	System Output (kWh/year)	System Price ($)	Payback Period (yr)	Emission Savings (MTCO2/yr)
Lot #3055 Design 1	2,235	448,105	$1,157,760	33	51.53
Lot #4015 Design 2	2,456	492,448	$1,272,330	33	56.63
Lot #3055 Design 2	5,666	1,136,209	$2,935,605	33	130.66
Lot #4015 Design 1	7,018	1,406,939	$3,029,238	27	161.80
Lot #4014 Design 2	8,071	1,618,155	$3,484,000	27	186.09
Lot #4014 Design 1	20,023	4,014,270	$6,914,400	22	461.64

As we suspected, parking structures are more expensive on a per watt basis compared to other solar systems due to the higher cost of materials and installation. In turn, they have payback periods that are generally longer than the average lifetime of a typical solar system. However, one exception can be found in Design 1 of Lot # 4014, which has the largest proposed installed area and system output. We can conclude that while a larger lot may correspond to a higher system price, it can also be more economically feasible as a long-term investment with its large capacity and shorter payback period. Likewise, a larger design would result in higher CO_2 emission savings and push the campus closer to its carbon neutrality goal.

XVI. Conclusion

This preliminary feasibility study of solar parking canopies at Cornell University evaluated six different lot designs to determine possible economic and environmental benefits of our proposal. We found that larger solar systems may make more sense economically as they have shorter payback periods while producing more clean electricity and reducing more emissions. However, we also established other benefits, such as dual use of the structures and appeal to the student body, that may make smaller structures valuable as well.

Although many precautions were taken, this preliminary study is not without its limitations. The biggest factor to consider are the many assumptions in our calculations. If this project were to move forward, we would propose redoing the analysis with exact measurements and known specifications from a potential contractor. Other future steps include conducting a more comprehensive survey of the student body to include more underclassmen to allow for a broader conclusion regarding the appeal of such solar parking canopy structures.

We hope this study leads to further exploration into creating a cleaner future at Cornell and provides further opportunities for more students to be involved in the design and implementation of green infrastructure on campus.

XVIII. Recommendations for Future Research

After completing our project, we have several recommendations for future research on the subject of solar canopy energy on Cornell's Campus:

1. An analysis on the infrastructure savings incurred from limiting the depreciation of parking lots by covering them with a solar canopy. How could fewer weather effects (exposure to sun and rain, salt after winter storms, etc) change the price of maintenance on the parking lots underneath?
2. A comprehensive Cornell community wide survey to determine the general interest in solar energy on campus and a more in depth answer to students' views on parking fees, in particular how they can be affected by large solar project construction. This could be combined with an educational component to teach students about the characteristics of a solar canopy structure and how it may have an effect on campus carbon emissions.
3. Our preliminary study found that the payback period of some of the designs may be longer than the life of the solar canopy system itself. What would be a reasonable addition to the parking price to make up for some of this loss? Or perhaps, could there be a surcharge for parking in a lot with the canopy since it provides protection from the sun, rain, or snow?
4. From a more social point of view, would it be possible to find potential donors to invest in a project such as this?

XX. Appendix A - Survey Questions

Survey Questions:

Question 1: Thank you for taking the time to fill out this survey! We are an interdisciplinary group of engineers and planners focusing on the viability of a solar canopy project on Cornell's Ithaca campus. Solar canopies are elevated structures which are typically installed over parking lots or other paved areas. Solar panels, placed on top of the structure, generate energy that is used for a variety of purposes. For example, electric car charging stations can be connected to the solar canopy to charge cars or the canopy can be connected to the local electrical grid to provide energy for buildings. We would like to gain insight on student and alumni interest in solar canopy technology on campus and potential parking lot locations to construct the project. The picture below illustrates an example of a solar canopy structure in a parking lot.

Question 2: What is your University affiliation?

Answers: Undergraduate Student, Graduate Student, Staff/Faculty, Alumni

Question 3: On a scale of 1-5, how much do you already know about solar energy?

Answers: None at all, A little, A moderate amount, A lot, A great deal

Question 4: How would you feel about having a large solar array on campus?

Answers: Very negatively, Negatively, Neutral, Positively, Very Positively

Question 5: Rank these factors as we consider a Cornell solar canopy project from most important (1) to least important (4).

Answers: How much power the system will produce (kW), How much carbon output the project will offset, How the project affects the aesthetics of the University's campus, How much it will affect the price of parking on campus.

Question 6: Rank these factors that would prevent you from supporting the solar canopy project on campus most important (1) to least important (4).

Answers: I am concerned about how much it will affect parking permit rates, I don't think Cornell should put resources into this type of project, I am worried that the solar array will affect the aesthetics of campus, I don't feel that I have enough information to make an informed decision.

Question 7: If you park on campus, which kind of parking permit do you have? (Displayed if "What is your University affiliation? = Staff/Faculty)

Answers: No-fee parking permit: North Campus A Lot, Paid parking permit, I don't have a parking permit but I park on campus.

Question 8: In which parking permit tier do you typically park?(Displayed if "If you park on campus, which kind of parking permit do you have?" = paid parking permit)

Answers: **Outer Tier Area:** A, E; **Perimeter Tier Area:** ME, O, R, WE; **Mid-Campus Tier Area:** C, G, HH; **Campus Tier Area:** D, J, L, N, P, U, Z

Question 9: If you park on campus, which type of parking permit do you have? (Displayed if "What is your University affiliation? = Undergraduate student OR "What is your University affiliation? = Graduate student)

Answers: Residential Parking Permit, Commuter Parking Permit, I don't park on campus, I don't have a parking permit but I park on campus.

Question 10: Which residential area is your assigned permit area? (Displayed if "If you park on campus, which kind of parking permit do you have?" = Residential parking permit)

Answers: **FH:** Hasbrouck Apt.; Thurston Court, **ND:** North Campus Residence Halls, Program Houses, and Cooperative Housing; 411 & 508 Thurston, **SW:** Cascadilla Hall; Sheldon Court; Eddygate;109 Sage Place; Schuyler House, **WD:** West Campus House System, Program Houses, and Cooperative Housing; 112 Edgemoor Lane.

Question 11: What kind of commuter permit do you have? (Displayed if "If you park on campus, which kind of parking permit do you have?" =Commuter parking permit)

Answers: **B Commuter Permit:** The B permit is valid all times in the B Lot near the Vet College, and in the north campus A Lot after 2:30 pm, **SC Commuter Permit:** The SC permit is valid in designated lots located along Campus Road, B Lot, CISER on Pine Tree Road, and A lot after 2:30 pm.

Question 12: If the presence of solar canopies over Cornell's parking lots would require parking fees to increase, would you be willing to pay more for your parking spot in exchange for shade/protection of your car and to help make Cornell Carbon Neutral?

Answers: Not willing, Could be convinced, Neutral, Willing, Extremely Willing

Question 13: Do you have any other thoughts on the potential solar canopy project that you would like to share with us?

Answer: Open ended text box

XXI. Appendix B - Pictometry Figures

Figure 25: Pictometry Estimation of Length of Lot #3055

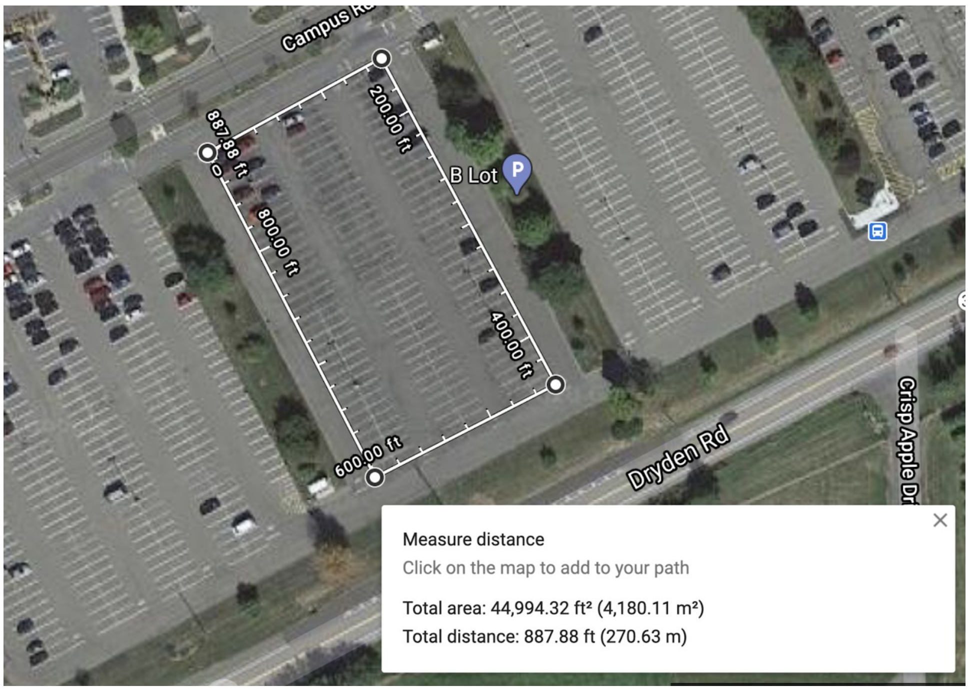

Figure 26: Pictometry Area Estimation of Smaller Rectangular Lot #4014

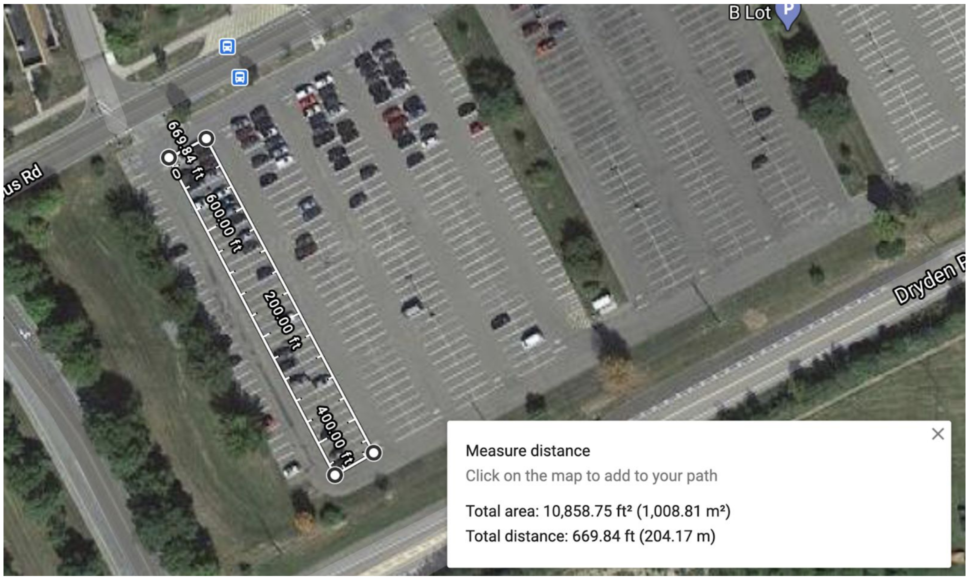

Figure 27: Pictometry Area Estimation of One Strip in Lot #4014

Figure 28: Pictometry Area Estimation of Lot # 4015

Figure 29: Pictometry Area Estimation of One Strip Lot # 4015

XXIII. References

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