Solar Farm Feasibility Study for Calvin University

ENGR 333 Section A

Professor Heun

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Abstract

With a goal of being carbon neutral by 2057, Calvin University is interested in using/producing renewable energy. Engineering 333 students explored different solar farm options. Various installation sites were analyzed, along with four different mounting options for solar panels: ground, rooftop, and carpark on-campus, and ground off-campus. The total carbon offset of Calvin's power usage covered by the projects was 21.04%. The most advantageous projects based on Internal Rate of Return (IRR) were the Venema Aquatic Center roof, VanNoord Arena roof, and Prince Conference Center roof with respective rates of 10.95%, 10.83%, and 10.02%.

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Introduction

The goal of this project was to analyze different possible opportunities for Calvin University to invest in a photovoltaic system to decrease Calvin's CO_2 emissions. This system was analyzed for four different project categories: on-campus ground mounting, on-campus rooftops, on-campus car parks, and off-campus. In analyzing the four categories, different sub-projects were also analyzed (i.e. different parking lots on campus for car parks). The Infrastructure and Modeling Team analyzed all these projects to estimate power output.

Results & Analysis

Table 1: Summary of Results for each Project

Group	Project	Total Power Output [kWhr/yr]	Initial Investment [$]	Total Investment per Watt Installed [$/W]	Payback Period [yrs]	IRR [%]	Carbon Offset [%]
On-Campus Ground	Lake Drive	202,076	243,006.68	1.63	18.0	3.99	0.39
	Lake Drive (Tree Removal)	629,602	672,614.71	1.45	14.0	7.11	1.21
On-Campus Rooftop	Venema Aquatic Center	500,490	465,725.43	1.26	11.5	10.95	0.96
	VanNoord	643,508	607,145.97	1.25	11.6	10.83	1.24
	Prince Conference Center	350,110	351,750.69	1.34	12.5	10.02	0.67
	DeVos/Business Building	253,462	290,139.23	1.57	14.3	8.54	0.49
	Hekman Library	349,410	369,952.69	1.46	13.1	9.43	0.67
On-Campus Carpark	Lot 1	735,769	772,821.99	1.37	17.0	4.72	1.42
	Lot 8	737,276	747,854.61	1.38	16.0	5.31	1.42
	Lot 13	779,331	799,638.54	1.33	17.0	4.91	1.5
	Lot 14	365,962	405,804.14	1.48	18.0	4.35	0.71
	Lot 15	504,218	547,390.16	1.42	18.0	4.39	0.97
	Lot 16	746,296	769,636.52	1.37	17.0	5.02	1.44
Off-Campus	Iron Wood Dr	4,125,036	3,514,001.97	0.83	21.0	3.27	7.95
*Green cells show the best project in each metric							

Two solar panels were selected based on size, with one smaller panel for rooftop mounting and one larger panel for all other projects. The factors that were primarily considered were power output, cost, and company stability for warranty purposes. Two CanadianSolar panels were selected due to the company's stability and the other factors considered. The TOPBiHiKu7 was selected as the larger panel and the TOPHiKu6 was selected as the smaller panel.

Table 2: Solar Panel Selection

Panel Type	Company	Power Output [W]	Panel Dimensions [mm x mm]	Panel Area [m2]	Cost Estimate [$/panel]
TOPBiHiKu7	CanadianSolar	705	2384 x 1303	3.11	168.48
TOPHiKu6	CanadianSolar	435	1722 x 1134	1.95	131.23

Progressions

For Calvin to implement a solar farm, there were two large considerations. First, the economic viability of the different projects, and second, the order in which they could be implemented. Thus, the projects were first ordered based on their economic viability. This list was then shortened by the physics team until there would be no electricity overproduction (Appendix F). With this finalized list, the projects were then reordered based on the age of the roof, so that roofs in need of repair the soonest were the first in the progression of all the projects. After these roofs, non-roof projects were then included, and lastly, roofs that did not need to be repaired soon. This finalized list includes the following, shown in Table 3.

Table 3: Recommended Progression Order

Progression Order	Project
1	Prince Conference Center
2	Devos Communication Cener
3	Hekman Library and Hiemenga Hall
4	Lake Drive Entrance
5	Seminary Field
6	Venema Aquatic Center
7	Van Noord Arena

Conclusion

To provide possible opportunities for Calvin University to invest in a photovoltaic system, on-campus ground mounting, on-campus rooftops, on-campus car parks, and off-campus solar systems were analyzed for energy production and economic feasibility. In analyzing the four categories, as well as the different sub-projects, it was found that a photovoltaic system could provide a 5.8% decrease in Calvin's carbon emissions while providing a payback period of 12 years. The solar panel farm can be the foundation of achieving Calvin's carbon neutrality goal.

Appendices

Appendix A. On-Campus Ground Mounting

Introduction

The On-Campus Ground Mounting team was responsible for determining possible locations within Calvin University's property limits for a solar farm ground emplacement in pursuit of achieving carbon neutrality. To accomplish this, the team analyzed multiple areas on campus based on factors such as available space, current use, sun exposure, ground conditions, accessibility for installation and maintenance, and ease of grid connection. An optimal location was identified through this and further analyzed, considering number of solar panels, mounting styles, shading, connecting to the grid, power output, and cost.

Results & Analysis

After conducting the initial stages of planning and research for available solar panel locations across the span of campus, the lot adjacent to Lake Drive on the North side of campus was selected as the top candidate to be pursued. This was an open, relatively flat lot that met the criteria introduced prior as well as having high visibility to the public, composed of an east and west side. Due to the small scale of the east side, the team focused solely on west side emplacement.

Two options within Lake Drive were chosen to be analyzed and are shown in Figure A.1. Option A considered removing a range of trees up to the detention pond to increase the area available and reduce shading concerns. Option B considered removal of only one to two trees, using the smaller available land space.

Figure A.1: (Left) Option A. (Right) Option B.

For ground mounting, two options were available and researched: standard or pole. Standard ground mounts are the more cost-effective option, using a metal framing driven into the ground to hold the panels up at a fixed angle, while pole mounts are a larger expense that support panels on a single pole. Despite pole mounts having a solar tracking system and a higher elevation that prevents obstructions, standard mounts allow for significantly more panels to be mounted and placed closer together. Standard mounts are also at a lower elevation, allowing for ease of maintenance. With these considerations, standard mounts were selected as optimal for the Lake Drive location.

With the location and mounting style identified, an analysis was conducted for each option using the CanadianSolar TOPBiHiKu7 solar panel (see Appendix H). Cost considerations for both options included transformers, inverters, wiring ran across the east to west side, gravel placed under the panels, and labor for panel installment. For Option A, significant tree removal estimates and land preparation were additionally considered as re-grading and landscaping are necessary. For Option B, tree removal estimates for one to two trees were considered due to their shading concerns. Protective measures such as fencing surrounding the panels were discussed but not considered in the cost calculations.

Option A offers a larger area with reduced shading, therefore greater energy generation. It requires a higher initial investment but achieves a lower cost per watt. Option B offers a smaller area with a lower initial investment but higher cost per watt. Depending on the decision-making criteria, Option A or Option B could be selected as the top choice. Based on power production, ROI, and payback period, Option A is the preferred choice.

Conclusion

The On-Campus Ground Mounting team identified the west side of the lot adjacent to Lake Drive as the optimal location for a solar farm due to its public visibility and physical suitability, where two options were analyzed. Options A and B are both good candidates, each having their own advantages and disadvantages.

Appendix A.1 Figures and Graphs

Table A.1: All Considered Options

Location	Advantages	Disadvantages
Field near Devos Center	- Open space - Exposure to visitors - Good sunlight - Proximity to electric grid	- Currently in-use (intramural sports) - Steep slope
Field near Phi Chi	- Wide open area - Good sunlight exposure	- Currently in-use (intramural sports) - Plans for building car park
Fieldhouse circle	- High visibility - Practical use of space	- Existing rocks/trees/flowers as decorations
Dewit Manor	- Some land availability	- Some trees in the way
Open Spaces on Campus Drive	- Use of extra space	- Safety concerns - Complications with easements (MDOT)
Nature Preserve	- Unused land	- Deforestation
Lake Drive East	- Open space with no trees - Verbal approval from Calvin CFO - High visibility	- Space not as large as West side - Sloped land
Lake Drive West	- Same advantages as Lake Drive East option - Large area - Promote Calvin sustainability goals through installation next to sign. - Not much shading/shadow issues during day-time	- One big tree to remove
Lake Drive West (Tree Removal)	- Same benefits as the option above. - Larger installation area - More kWh/yr	- Deforestation - Deforestation costs - Higher up-front land preparation cost

	Standard Ground-Mounts	Pole-Mounts
Pro #1	Typically less expensive than pole-mounted systems	Tracking allows pole mounts to rotate, maximizing exposure
Pro #2	Easier to install and maintain than pole-mounted systems	Tracking system tilts panels according to time of day and season
Pro #3	Can use alternative mounting if the ground is too hard for poles	Takes up less surface area on your property
Con #1	Fixed tilt angle limits how much sunlight panels can absorb	Often cost more due to the tracking system and complex setup
Con #2	Standard mount systems don't work well with areas prone to snow	Tend to require more maintenance
Con #3	Possibly a higher risk of damage due to wildlife or vandalism	The electricity needed to operate the tracking system may not be worth the added benefits

Figure A.2: Advantages and Disadvantages of Standard and Pole Mounting

Figure A.3: Option A (tree removal) Solar Panel Modeling

Figure A.4: Option B (current land) Solar Panel Modeling

Table A.2: Data Summary of Each On-Campus Ground Project

Project	Total Initial Invest ($)	First Year Energy (kWh/$)	Payback Period (yr)	30-year Profit ($)	30-year ROI (%)	TCI/W ($/W)	GHG Reduction (%)	IRR (%)
Lake Drive (Trees Removed)	672,614.71	0.936	14.0	423,175.61	0.8	1.45	1.21	7.11
Lake Drive	243,006.68	0.832	18.0	32,330.44	-17.9	1.63	0.39	03.97

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Appendix B On-Campus Rooftop Mounting

Introduction

The On-Campus Rooftop team was responsible for generating an in-depth assessment of rooftops that are viable for solar panel installation based on the potential environmental impact and energy savings. Buildings will be analyzed individually, and then the best options will be listed based on total investment, total investment per watt, first year energy, payback year, return on investment, carbon neutrality, and internal rate of return.

Procedure

To analyze the buildings on Calvin's campus, a list was formed of all the optimal rooftops that appeared to have the best chance of creating the most power-dense system. This preliminary assessment was based on the size, surroundings, accessibility, and age of the roof. The following buildings were chosen Huizenga Tennis and Track Center (TNT), VanNoord Arena, Venema Aquatic Center, Football Locker Room, Covenant Fine Arts Center (CFAC), Prince Conference Center, DeVos Communications Center, Business Building, North Hall, Hekman Library, Hieminga Hall, and the Dorms.

After sending the list to ENGR 327, a structural civil engineering class, the list was slimmed down based on the physical capabilities of each of the buildings. The first building eliminated from the list was the TNT. This building contains a relatively new but thin sheet metal roof that would not withstand any additional weight. Due to the overall construction of the roof, the CFAC suffered from a similar problem and was also removed from consideration. The next building to be removed from the list of considerations was all of the dorms. While the dorm roofs have a large, combined surface area, their location is amongst many trees that will hinder electricity production from solar panels. Additionally, there are many obstructions on the top of the roof, which significantly would limit the number of solar panels that can be installed. The final building removed from consideration was the football locker room. This location is a new building near the soccer field which is located low to the ground making it vulnerable to incoming soccer ball projectiles. The size of the roof also only allows for a small amount of solar panels to be placed upon it making its cost outweigh its energy output.

After excluding the previously stated roofs, the available area, roof type, and slope for the remaining roofs were discovered and sent to the infrastructure team to develop the most efficient solar array. These are attached in Table B.1 in the following appendix.

To determine the correct layout for the solar panel arrays for each of the roofs, fire codes needed to be considered based on commercial standards rather than residential ones. The ICC digital codes centered around Centerline Pathways, Edge Pathways, and Interior Pathways stated that each array needed a no smaller than 4-foot-wide pathway along the x and y axis centerlines, as well as a 3-

foot-wide path along the edge of the roof, and finally a 4-foot-wide pathway is required for every 150 ft of solar panels. All of this information is listed below in Appendix B.1.

Choosing a solar panel for the rooftop arrays proved to be a unique challenge. The space constraints given by the overall geometry of the buildings were considerably complex. Additionally, obstructions such as air vents or air control units had to be designed around to adhere to fire codes. Two different sizes of panels were evaluated to see which would be the best option in terms of $/kWh, the TOPBiHiKu7 and the TOPBiHiKu6. It ended up being more efficient to use the smaller TOPBiHiKu6 solar panel given the sheer number that would be able to fit on each of the roofs. Each panel has a unit cost of $131.23 and is capable of producing 440 Watts of electricity.

Results

One of the key relations discerned from the data is that the ROI is largely dependent on the size of the solar panel array and the respective rooftop size. Smaller roofs will ultimately have a lower initial investment cost while larger projects will supply enough power to decrease the payback period. As a result, the ideal project balances both the total capital and operating costs with the funds generated throughout the lifespan of the solar array. The calculated value for each of the considered roofs can be found in Table B.2, which highlights how the Venema Aquatic Center would be best choice financially.

Roof top solar arrays offer a great way to utilize the space that has already been developed on campus. The fact that the rooftops already have money set aside for being repaired means that the overall ROI is higher than most other projects, making this project slightly more financially viable than the others. Additionally, having solar panels on the roof tops on campus will be a visual demonstration of Calvin's commitment to sustainability. Visitors visiting Calvin will see the solar panels and gain a good impression of Calvin's work towards becoming a greener campus.

Conclusion

The goal of this project was to determine which roofs could provide the most amount of clean renewable energy at a reasonable cost. Due to efforts from the infrastructure team, the civil class, and the produced cost-calculator, the top three roofs would include the VanNoord Arena, Venema Aquatic Center, and DeVos Communications Building. The solar panels placed onto these roofs will help Calvin University move closer to its goal of carbon neutrality.

Appendix B.1 Figures and Graphs

Table B.1: Information Sent to the Infrastructure Team

Location	Roof Type	Area (ft^2)	Slope
CFAC	Flat	13492	0:0
Venema	Angled	20291	6:12
VanNoord	Angled	26426	6:12
Hekman	Flat	32847	0:0
DeVos/Business	Flat	25528	0:0
Prince	Flat	41700	0:0

Table B.2: Overall Results

Building	Total Initial Investment ($)	Total Initial Investment Per Watt ($/W)	First Year Energy (kWh/$)	Payback (years)	ROI (%)	CN (%)	IRR (%)
Venema	465,725.43	1.26	1.075	11.50	89.33	0.96	7.72
VanNoord	607,145.97	1.25	1.060	11.61	89.19	1.24	7.60
DeVos/ Business	290,139.23	1.57	0.874	14.30	63.52	0.49	5.38
Prince	351,750.69	1.34	1.005	12.50	79.75	0.67	6.25
Hekman	369,952.69	1.46	0.944	13.10	73.89	0.67	6.81
Total	**2,084,714.01**	**6.88**	**4.958**	**14.30**	**80.00**	**4.03**	**6.82**

605.11.3.3.2 Pathways.

The solar installation shall be designed to provide designated pathways. The pathways shall meet the following requirements:

1. The pathway shall be over areas capable of supporting the live load of fire fighters accessing the roof.
2. The centerline axis pathways shall be provided in both axes of the roof. Centerline axis pathways shall run where the roof structure is capable of supporting the live load of fire fighters accessing the roof.
3. Shall be a straight line not less than 4 feet (1290 mm) clear to skylights or ventilation hatches.
4. Shall be a straight line not less than 4 feet (1290 mm) clear to roof standpipes.
5. Shall provide not less than 4 feet (1290 mm) clear around roof access hatch with at least one not less than 4 feet (1290 mm) clear pathway to parapet or roof edge.

Figure B.1: National Fire Code for Rooftop Solar Panels

RS402.4.1 (R324.6.1) Pathways.

Not fewer than two pathways, on separate roof planes from lowest roof edge to ridge and not less than 36 inches (914 mm) wide, shall be provided on all buildings. Not fewer than one pathway shall be provided on the street or driveway side of the roof. For each roof plane with a photovoltaic array, a pathway not less than 36 inches wide (914 mm) shall be provided from the lowest roof edge to ridge on the same roof plane as the photovoltaic array, on an adjacent roof plane, or straddling the same and adjacent roof planes. Pathways shall be over areas capable of supporting fire fighters accessing the roof. Pathways shall be located in areas with minimal obstructions such as vent pipes, conduit, or mechanical equipment.

Figure B.2: ICC Fire Codes

1205.3.2 Interior pathways.

Interior pathways shall be provided between array sections to meet the following requirements:

1. Pathways shall be provided at intervals not greater than 150 feet (45 720 mm) throughout the length and width of the roof.
2. A pathway not less than 4 feet (1219 mm) wide in a straight line to roof standpipes or ventilation hatches.
3. A pathway not less than 4 feet (1219 mm) wide around roof access hatches, with not fewer than one such pathway to a parapet or roof edge.

Figure B.3: ICC Fire Codes

Figure B.4: Venema Aquatic Center

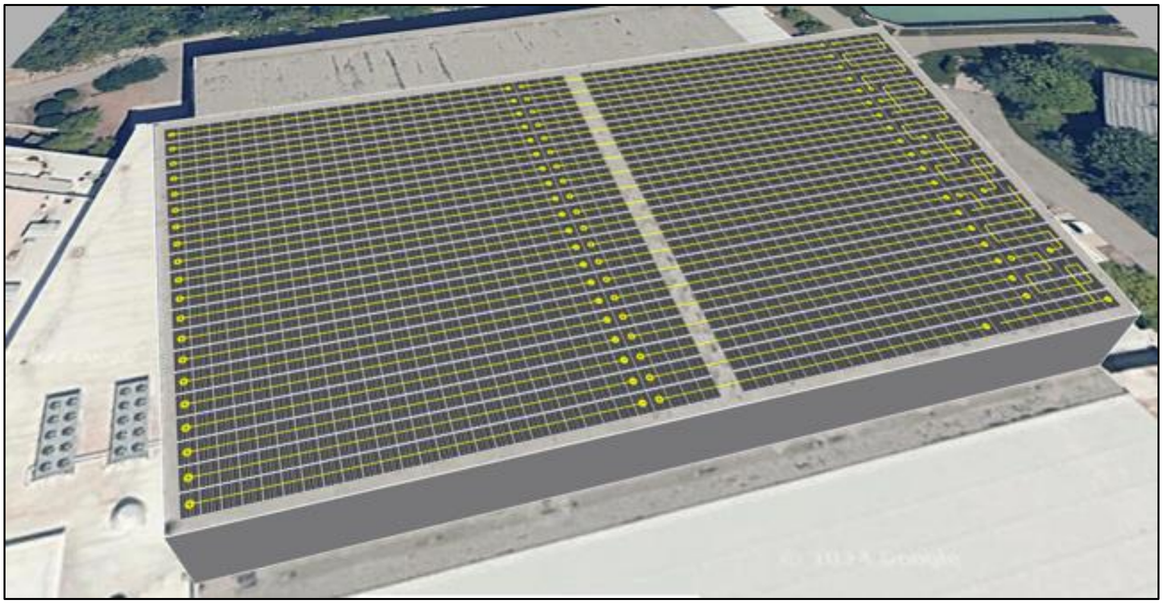

Figure B.5: VanNoord Arena

Figure B.6: DeVos Communications Center and Business Building

Figure B.7: Prince Conference Center

Figure B.8: Hekman Library

Appendix B.1 Sources

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Appendix C. On-Campus Carpark Mounting

Introduction

The car park team focused on creating a solar structure that would be built over the existing parking lots across Calvin's Campus. Creating a solar car park is expensive when compared to other methods of producing PV electricity. This is due to the structures required to mount the PV panels which are much more substantial than the infrastructure required for ground-mount or rooftop-mounted arrays. Apart from being expensive, there are a few other factors that make carpark-mounted solar arrays desirable such as efficient land use since it is reusing land that is already being used. Further, car parks create a draw for students, visitors, faculty, and staff, as the structures provide shading for parking spots during hot summer months, and protection against harsh weather conditions, including rain, snow, and hail. The car park team worked alongside the performance analysis team to analyze which parking lots would provide the largest return on investment (ROI). To do this, the number of parking lots, number of panels per parking lot, and panel type were all calculated. The total cost of the system was calculated, including panel cost, structure cost, labor/installation cost, operation and maintenance costs, and shipping costs.

Results & Analysis

Optimal parking lots were chosen using a few important factors. These factors include natural shading, the number of parking spaces, as well as parking lot direction. Each parking lot was analyzed, and feasible parking lots for solar structures were chosen using said criteria. These parking lots are lots: 1, 8, 13, 14, 15, and 16 (See Figures C.1-7). Secondly, the orientation and height of panel structures had to be found. Through research, it was found that generally, solar car parks can have a maximum panel angle of 5 degrees to 15 degrees which was also true of the manufacturer the team had decided would be the best fit for the needs of Calvin University, Sun For Sun. Secondly, the minimum height of the system needed to be decided. To maintain the parking lot's functionality, a minimum height of 12 feet was decided so that snow plowing would not be restricted by the structures. Solar panels were chosen through research, taking into consideration company stability, warranty, efficiency, and cost. Through research, the Canadian Solar BiHIKu7 655W Panels were chosen. Further, pole-mounted systems were considered as a second option, rather than designing a system that ran along parking spots. The advantage of pole mounting is that all panels can face south, as well as the angle could be increased to a more optimal value. Through research, this option was found to not be as efficient, due to the smaller number of panels that could be installed in the parking lot. This information was passed to the performance and modeling team, who found specific data regarding the number of panels, and total system output. The performance team modeled solar structures in Sunny Design, which provided the information needed to calculate decided metrics.

Panel costs (per watt) were found from A1 Solar Store. Structural costs and shipping were found (per watt) through contacting Sun for Son. Labor/Installation Costs (per watt) were estimated from installation costs (per watt) using quoted data provided by Agathon Solar. Operation and Maintenance Costs were estimated using data from HowMuch. Cost data can be seen in Table C.1. Through analyzing the data, it was decided that parking lot 8 is the best project option. Parking lot 8 has the highest ROI, lowest payback period, and the highest first-year energy. Parking lot 8, although similar in size to other parking lots, has the highest energy value due to it facing southwest, while other parking lots are facing either directly east or west. The southwest-facing panels allow for more sun time, as well as more direct sun during the peak payment hours (time when electricity is most expensive). These factors make lot 8 the best option. If a project with a low initial value is needed, parking lot 14 is the best option, because it is the smallest in size, providing the lowest initial cost. Lots 1, 13, and 16 are also very good project options, that could be added to parking lot 8 to create a larger project, with higher output.

Conclusion

This project aimed to create a solar structure model that would be built over the existing parking lots across Calvin's Campus. These calculations would consider costs, energy output, and carbon neutrality values. Overall, Parking Lot 8 is the recommended project for a solar car park, with lots 1, 13, and 16 being secondary parking lot options. Lot 14 has the cheapest initial cost but has lower return on investment, carbon emissions, and investment per watt. Implementing these recommendations to create a solar system at Calvin would reduce energy costs and help Calvin move closer to achieving carbon neutrality.

Appendix C.1 Figures and Graphs

Table C.1: Summary of Cost Analysis

Parking Lot	Total Initial Investment ($)	Total Initial Investment Per Watt ($/W)	First Year Energy (kWh/$)	Payback (years)	ROI (%)	CN (%)	IRR (%)
Lot 1	772,821.99	1.37	0.952	17.0	-12.7	1.42	4.72
Lot 8	747,854.61	1.38	0.986	16.0	-9.6	1.42	5.31
Lot 13	799,638.54	1.33	0.975	17.0	-11.6	1.50	4.91
Lot 14	405,804.14	1.48	0.902	18.0	-15.1	0.71	4.35
Lot 15	547,390.16	1.42	0.921	18.0	-14.6	0.97	4.39
Lot 16	769,636.52	1.37	0.970	17.0	-11.1	1.44	5.02
Total	4,043,145.96	8.35	5.706	17.167*	-12.45*	7.46	4.78*

* indicates an average calculation, rather than a summation

Figure C.1: Lot 1

Figure C.2: Lot 8

Figure C.3: Lot 13

Figure C.4: Lot 14

Figure C.5: Lot 15

Figure C.6: Lot 16 Part 1

Figure C.7: Lot 16 Part 2

Appendix C.2 Sources

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Appendix D. Off-Campus Ground Mounting

Introduction

The Off-Campus Ground Mounting team was responsible for analyzing possible off-campus solutions in order to achieve Calvin's University's goal of carbon neutrality. In order to do this, the group analyzed a twelve-acre property in Allendale, Michigan. Many aspects of implementation were considered to analyze this property including solar panel type, mounting, and connecting to the grid. In addition to the implementation, government incentives and sell-back prices over the years were also considered for the analysis to make a cost calculator of the system as a whole. This calculator was built by the ground off-campus group, and the design is shown in Appendix D.1. The goal of the cost calculator was to get initial investment compared to power output, return on investment, and the payback period for the farm.

Results & Analysis

This property was chosen for analysis by the off-campus group for its location and acreage (figure D.1). Along with that the property was also chosen because it was advertised with "heavy electric" on the land and it was zoned industrial, which is required in order to have a solar farm on the land.

Figure D.1: Project Location

In order to run the analysis on the off-campus property, the solar panel that was used was the CanadianSolar TOPBiHiKu7 (see Appendix H for data sheets). The mounting that the group decided on was the fixed ground mounting due to the decreased cost and complexity of installation. A more complex system was considered, but due to the cost of variable angle mounting and the size of the solar farm, it was not chosen. Connecting to the grid is more complicated for off-campus solar farms because the farm would become a power producer and need to be in an agreement with consumer's energy. To connect to the grid, the farm needed an inverter and a transformer to convert the solar energy into usable energy for the grid. The array can be seen in Appendix D.3 below.

Government incentives were also a topic that was researched for the analysis of the off-campus ground mounting solar farm. The US has a 30% match tax incentive for solar farms, but by 2035 it will no longer exist (Washington). The incentive is based on the total initial investment on all costs to start a solar farm. When looking for state specific incentives, there were none found for the state of Michigan.

Another main factor when implementing a solar farm is the selling rate back to the electric grid. This is a variable rate for residential systems versus a solar farm. Since predictions on future sell back rates are not published, the team decided to use the historical data on sell back prices. The rate that the team concluded was between $0.04 per kW-hr and $0.10 per kW-hr.

When comparing to other groups the ground off campus group excelled at clean energy production. This project had the best carbon offset numbers because of the size of the location. The off-campus project is a good choice if the intention of the solar project is to minimize Calvin's carbon footprint. This project would prove to be the most ideal to ensure Calvin's 2057 carbon neutrality goal. The costs for our project were very high and this was mainly due to the expensive costs of buying land and prepping that land for solar panels.

Conclusion

The off-campus location of Ironwood was chosen for its location, size, and amenities offered. Due to the fact that this land needs to be purchased, it made more of the financial metrics for this location look not as ideal as other projects considered. This project excels in the total carbon offset and price per kWh due to the sheer size of the 12-acre plot of land.

Appendix D.1 Sources

Washington, K. (2024, March 7). The Solar Tax Credit: What It Is And How To Claim It. *Forbes Advisor*. https://www.forbes.com/advisor/taxes/solar-tax-credit/

Appendix D.2 Initial design to the Cost Calculator

These values are not final but more for structured representation

Final Off Campus Calculations

Calculator 1

Total Initial Investment

Solar Panel	655MB-AG BiHiKu	
cost of a solar panel	0.27	$ / W
bulk discount	3%	% off / panel
final price for a solar panel	0.2619	$ / panel
# of solar panels	4400	panels
Power	655	W/panel
Shipping cost per panel	$ 10	$/panel
Shipping cost	$ 44,000	
Total Solar Panel Cost	$ 822,140	

Inverters	SC 2800 UP-US	
cost of an inverter	221000	$ / inverter
# of inverters	1	inverters
life expectancy	12	years
Total Inverter Cost	$ 221,000	

Land Preparation Costs	GR Property	
Tree Removal	20000	$
Land Leveling	45000	$/acre
Total Leveling	450000	$
Structures for Solar Panel	1200	$/6 panels
Total Structure Cost	880000	$
Buying Land	1000000	$
Total Land Costs	$ 2,350,000	

Connecting to the Grid	GR Property	
Transformer	0	$
Transmission Line Cost	42636.14114	$/mi
Line length	1	mi
Wiring Cost	42636.14114	$
Interconnection Fee	6500	$
Application Fee	300	$
total CTTG cost	$ 49,436.14	

Safety Switches		
Switches Cost	26000	$
# of safety switches	1	safety switch
Total Safety Switches Cost	$ 26,000.00	

Initial incentives		
tax incentive (off investment)	0.3	%
tax refund	1032773	$
donations	30000	$
Total cash off	$ 1,062,772.84	

Total Initial Investment	$ 2,405,803

Total initial production (year 1)

Sun	Grand Rapids	
peak hours	3.96	hrs
Solar Panel Efficiency	23%	
Inverter Efficiency	98%	
operational hours	1445.4	hrs/yr

Installed Capacity	2882000	W
Capacity with efficiency	662860	W

Total Plant production	2.65	MW
Total Plant production	3832480	kWhr/yr

Yearly cost

Land	GR property	
Mowing / snow removal	50000	$/yr
taxes	8000	$/yr
total land cost	58000	$/yr

Ops and maintenance		
cost per kW	14.14	$ / kW
cost per kwhr	0.009782759	$/kW-hr
total cost	37492.22859	$ / yr

total cost per year	$ 95,492.23	$/yr

Figure D.2: Initial Investment, Initial Production, and Yearly Cost

Life Capabilities Calculator

30 year plan factors

Return on production		
return on each kWh	0.0600	$/kWhr

Production		
degradation / yr (solar panel)	0.40%	%/yr
degradation / yr (inverter)	0.40%	%/yr

Time Value of Money		
interest	8%	annual
inflation	3%	annual

Figure D.3: Life Capabilities Calculator

Figure D.4: PV and FV Calculator

Year / Production			present value of money calculations						future value calculations			
year (date)	year after investmen	power output [kWh / yr]	investment [$/year]	Cost [$/year]	total cost [$/year]	$ made from the farm / year	ROI / year (PVM)	Cumulative Cash Flow	total cost [$/year]	$ made from the farm / year	ROI / year (FVM)	Cumulative Cash Flow
2025	0	3832480.0	$ 2,405,803.30	$ 95,492.23	$ 2,501,295.53	$ 229,948.80	$ (2,271,346.73)	$ (2,271,346.73)	$ 2,501,295.53	$ 229,948.80	$ (2,271,346.73)	$ (2,271,346.73)
2026	1	3801881.5	$ -	$ 95,492.23	$ 95,492.23	$ 228,112.89	$ 132,620.66	$ (2,138,726.07)	$ 98,357.00	$ 234,956.28	$ 136,599.28	$ (2,134,747.45)
2027	2	3771405.6	$ -	$ 95,492.23	$ 95,492.23	$ 226,284.34	$ 130,792.11	$ (2,007,933.96)	$ 101,307.71	$ 240,065.05	$ 138,757.35	$ (1,995,990.10)
2028	3	3741052.4	$ -	$ 95,492.23	$ 95,492.23	$ 224,463.14	$ 128,970.91	$ (1,878,963.05)	$ 104,346.94	$ 245,276.94	$ 140,930.00	$ (1,855,060.10)
2029	4	3710821.8	$ -	$ 95,492.23	$ 95,492.23	$ 222,649.31	$ 127,157.08	$ (1,751,805.97)	$ 107,477.34	$ 250,593.75	$ 143,116.41	$ (1,711,943.69)
2030	5	3680713.8	$ -	$ 95,492.23	$ 95,492.23	$ 220,842.83	$ 125,350.60	$ (1,626,455.37)	$ 110,701.66	$ 256,017.36	$ 145,315.70	$ (1,566,627.99)
2031	6	3650728.5	$ -	$ 95,492.23	$ 95,492.23	$ 219,043.71	$ 123,551.48	$ (1,502,903.89)	$ 114,022.71	$ 261,549.64	$ 147,526.93	$ (1,419,101.06)
2032	7	3620865.8	$ -	$ 95,492.23	$ 95,492.23	$ 217,251.95	$ 121,759.72	$ (1,381,144.17)	$ 117,443.40	$ 267,192.49	$ 149,749.10	$ (1,269,351.97)
2033	8	3591125.7	$ -	$ 95,492.23	$ 95,492.23	$ 215,467.54	$ 119,975.32	$ (1,261,168.86)	$ 120,966.70	$ 272,947.84	$ 151,981.14	$ (1,117,370.83)
2034	9	3561508.3	$ -	$ 95,492.23	$ 95,492.23	$ 213,690.50	$ 118,198.27	$ (1,142,970.59)	$ 124,595.70	$ 278,817.63	$ 154,221.93	$ (963,148.89)
2035	10	3532013.6	$ -	$ 95,492.23	$ 95,492.23	$ 211,920.81	$ 116,428.59	$ (1,026,542.00)	$ 128,333.57	$ 284,803.85	$ 156,470.28	$ (806,678.61)
2036	11	3502641.4	$ -	$ 95,492.23	$ 95,492.23	$ 210,158.49	$ 114,666.26	$ (911,875.74)	$ 132,183.58	$ 290,908.50	$ 158,724.92	$ (647,953.69)
2037	12	3648521.0	$ 221,000.00	$ 95,492.23	$ 316,492.23	$ 218,911.26	$ (97,580.97)	$ (1,009,456.71)	$ 451,242.24	$ 312,115.11	$ (139,127.13)	$ (787,080.82)
2038	13	3618658.3	$ -	$ 95,492.23	$ 95,492.23	$ 217,119.50	$ 121,627.27	$ (887,829.45)	$ 140,233.56	$ 318,847.30	$ 178,613.74	$ (608,467.08)
2039	14	3588918.2	$ -	$ 95,492.23	$ 95,492.23	$ 215,335.09	$ 119,842.87	$ (767,986.58)	$ 144,440.56	$ 325,713.65	$ 181,273.09	$ (427,193.99)
2040	15	3559300.8	$ -	$ 95,492.23	$ 95,492.23	$ 213,558.05	$ 118,065.82	$ (649,920.76)	$ 148,773.78	$ 332,716.48	$ 183,942.70	$ (243,251.29)
2041	16	3529806.1	$ -	$ 95,492.23	$ 95,492.23	$ 211,788.36	$ 116,296.13	$ (533,624.62)	$ 153,236.99	$ 339,858.15	$ 186,621.16	$ (56,630.14)
2042	17	3500433.9	$ -	$ 95,492.23	$ 95,492.23	$ 210,026.04	$ 114,533.81	$ (419,090.82)	$ 157,834.10	$ 347,141.04	$ 189,306.93	$ 132,676.80
2043	18	3471184.4	$ -	$ 95,492.23	$ 95,492.23	$ 208,271.07	$ 112,778.84	$ (306,311.98)	$ 162,569.13	$ 354,567.55	$ 191,998.42	$ 324,675.22
2044	19	3442057.6	$ -	$ 95,492.23	$ 95,492.23	$ 206,523.46	$ 111,031.23	$ (195,280.75)	$ 167,446.20	$ 362,140.13	$ 194,693.93	$ 519,369.15
2045	20	3413053.4	$ -	$ 95,492.23	$ 95,492.23	$ 204,783.20	$ 109,290.97	$ (85,989.78)	$ 172,469.59	$ 369,861.24	$ 197,391.66	$ 716,760.81
2046	21	3384171.8	$ -	$ 95,492.23	$ 95,492.23	$ 203,050.31	$ 107,558.08	$ 21,568.30	$ 177,643.67	$ 377,733.39	$ 200,089.71	$ 916,850.52
2047	22	3355412.9	$ -	$ 95,492.23	$ 95,492.23	$ 201,324.77	$ 105,832.54	$ 127,400.85	$ 182,972.98	$ 385,759.08	$ 202,786.10	$ 1,119,636.62
2048	23	3326776.6	$ -	$ 95,492.23	$ 95,492.23	$ 199,606.60	$ 104,114.37	$ 231,515.22	$ 188,462.17	$ 393,940.89	$ 205,478.71	$ 1,325,115.33
2049	24	3464561.9	$ 221,000.00	$ 95,492.23	$ 316,492.23	$ 207,873.72	$ (108,618.51)	$ 122,896.70	$ 643,363.54	$ 422,564.46	$ (220,799.07)	$ 1,104,316.26
2050	25	3435435.1	$ -	$ 95,492.23	$ 95,492.23	$ 206,126.10	$ 110,633.88	$ 233,530.58	$ 199,939.52	$ 431,582.29	$ 231,642.77	$ 1,335,959.02
2051	26	3406430.9	$ -	$ 95,492.23	$ 95,492.23	$ 204,385.85	$ 108,893.62	$ 342,424.20	$ 205,937.71	$ 440,776.74	$ 234,839.04	$ 1,570,798.06
2052	27	3377549.3	$ -	$ 95,492.23	$ 95,492.23	$ 202,652.96	$ 107,160.73	$ 449,584.93	$ 212,115.84	$ 450,150.79	$ 238,034.95	$ 1,808,833.01
2053	28	3348790.4	$ -	$ 95,492.23	$ 95,492.23	$ 200,927.42	$ 105,435.19	$ 555,020.12	$ 218,479.31	$ 459,707.41	$ 241,228.10	$ 2,050,061.11
2054	29	3320154.1	$ -	$ 95,492.23	$ 95,492.23	$ 199,209.24	$ 103,717.02	$ 658,737.14	$ 225,033.69	$ 469,449.63	$ 244,415.94	$ 2,294,477.05

Appendix D.3 Location Solar Array

Figure D.5: Proposed Solar Array on Location

Appendix E. Infrastructure and Modeling

Introduction

The Infrastructure and Modeling team was responsible for developing virtual models to understand the feasibility and efficacy of solar panels for each group's proposed locations. Other responsibilities included communicating with the other teams to ensure accuracy in modeling their systems and developing estimates for the energy production of each potential project. All project models found throughout this report were developed by the Infrastructure and Modeling team and were handed off to each other team for their use.

Procedure

To begin modeling the projects, certain information was needed from each team. First, they needed to provide a summary of their top potential solar array sites. Then, for each site, they needed to find information about the height and slopes of each roof/surface, the spacing required between panels to adhere to fire and safety codes, and the ideal angle for mounting the panels.

Next, to model each team's PV arrays, a PV planning software called Sunny Design was used. Sunny Design allows users to define buildings with specific roof heights, slopes, and shapes. This even includes the ability to add inconsistent obstructions such as HVAC equipment. Sunny Design also allows users to customize the spacing from panel to panel as well as from panel to roof edge. This allows for the inclusion of the fire and safety restrictions that were previously mentioned.

In general, panels on sloped roofs/surfaces were laid flat on those surfaces, making their angle equal to the slope of the roof. For flat roofs, a tilt angle of 37° was used, an ideal value determined from an online calculator (LINKIGNING). When possible, azimuth angles were chosen to face directly south, maximizing power production, but often they were chosen to match the building's roof lines to maximize area coverage and aesthetics. With the roof surfaces defined and a specific solar panel model provided, Sunny Design automatically fills the surface with panels in accordance with the design specifications. The peak power figures for each project are calculated by Sunny Design based on the number of panels fitted to each surface. The models for each site with PV panels arranged were given to each team to present in their respective portions of the report.

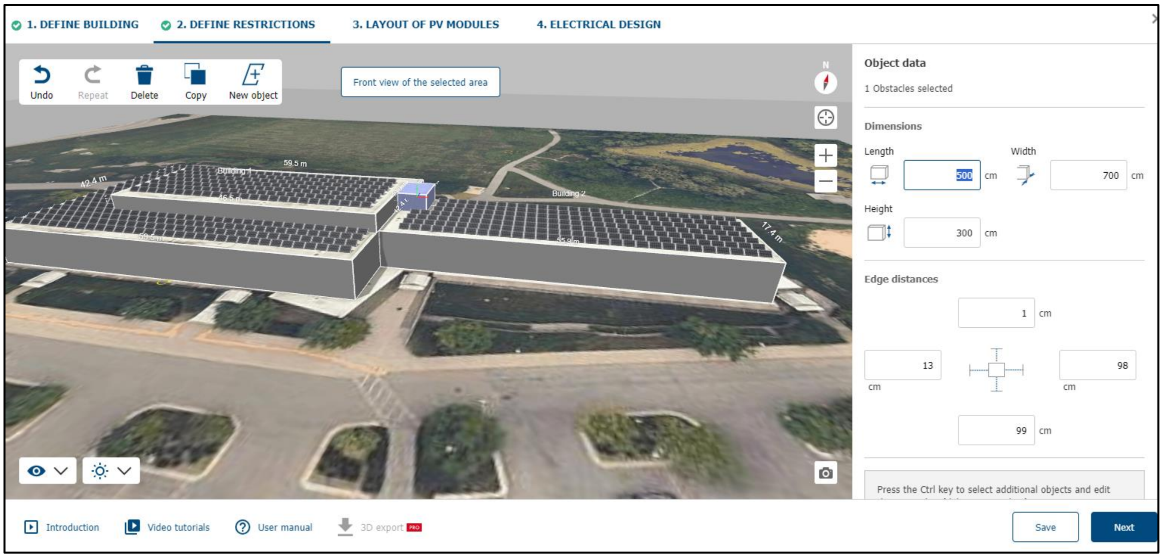


Figure E.1: Example building model in Sunny Design

With the PV panels laid out and models approved by each group, the inverters were configured for each project to calculate the annual energy production of that project. Using the inverter options present in the Sunny Design software, larger wattage inverters were selected to encompass as many panels as possible with small ones used to complete the arrays.

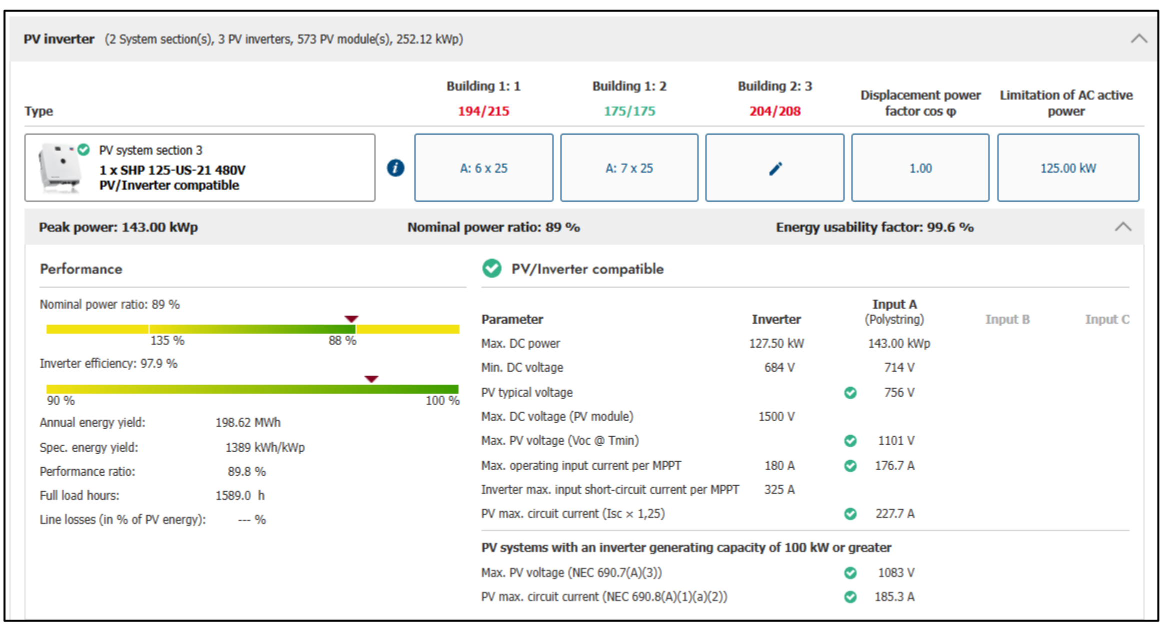


Figure E.2: Example Inverter Structure

All of this information would be shared with the various groups so that they could develop estimates for the cost per kilowatt-hour for each project site. Our team also looked into costs of the PV panels that were selected, the costs of the inverters, and the cost of transformers for each array so that each group could factor those costs into their calculators. The panel costs were determined from PV panel suppliers' bulk pricing. Similarly, inverter costs were calculated using prices from inverter suppliers' pricing. Transformer costs were estimated by determining the number of panels the selected transformer could support. Given the price of a single transformer, the total transformer cost of each array was then calculated by the proportion of panels the array contained to the number of panels the transformer could support. This was then multiplied by the single transformer cost to get a value for the total number of transformers needed and total transformer cost for that array. Estimates for solar panel weight were given to the Civil engineering class so that they could complete their work. All sources for cost estimation are shown in the following table:

Table E.1: Infrastructure and Modeling Sources

Component Cost/Value	**Source**
Tilt Angle	https://profilesolar.com/locations/United-States/Grand-Rapids
Panels	Canadian Solar
Inverters	SMA Solar Technology
Transformers	Brett Hoogewind, Calvin Associate Director of Facilities

Conclusion

In short, by using specific data from each group category, a proper model for each proposed location was developed. These models included complete panel arrays with their custom inverter designs. As a result, peak power outputs and energy production could be calculated and handed off to their respective groups. Additionally, transformer costs for each project were calculated and also returned to each team.

Appendix F. Physics 131

Introduction

The physics 131 class provided with the following problem: "Given the attached datasheets for all proposed solar farm designs, A) determine the optimal tilt angle for adjustable designs, and calculate B) a projection of the monthly peak and overall power produced by each farm design throughout the year, C) a model of the impact made on Calvin's electrical billing during peak hours and throughout the year."

Methods

To solve this problem, Professor Molnar created a program in python for the students to use during lab. The program included 4 main inputs: the orientation of the solar panels, the orientation of the sun, real weather data, and the electric bill data. The orientation of the panels was provided by ENGR 333 and included tilt and azimuth angles. There were some angles that were fixed and some angles that were varied to optimize the system. The orientation of the sun was input as vectors and used to determine extinction and how much sunlight would hit the solar panels. The real weather data was provided by Professor Molar from his personal solar system and was used to model as accurately as possible the weather conditions expected in western Michigan. These three inputs combined allowed the production of the solar farm to be modeled. Finally, the electric bill data was used to determine how much Calvin would save on electricity given the modeled production of the farm.

During the lab the students used this program to optimize the solar farm for maximum savings. To optimize the system, the students varied the azimuth and tilt angles that were not fixed. Once the max savings were found the results were given to the ENGR 333 class.

Results

Using the seven-step progression given by ENGR 333, a file was set up by Professor Molnar to calculate the deliverables. The progression can be found in Table F.1, with the values shown as a [-1] able to be varied. This is found in Figure F.2. From this progression, Figures/Tables F.3-F.6 are created.

Figure F.3 illustrates the daily electricity from grid for Calvin before and after implementation of the full progression. The graph depicts how in the middle of the day where the sun is above the panels, the energy Calvin produces can encompass its full need for a period.

Figures/Tables F.4-F.5 show the peak kW purchased and billing information. The graphs are very similar as with a higher peak, the billing will increase, thus with a decrease in the peak of the peak kW shown well in the summer months, the billing will follow.

Table F.6 is the summary table with the Energy produced, Savings in M$, and in GWh. The loss column also shows the efficiency to Calvin's needs with a loss of only 0.001 throughout the entirety of the year.

Conclusion

The physics team was able to take part in the solar project in a major way, by taking on the role of energy production and savings from the energy bill. By using the code written by Professor Molnar and numbers optimized by the class, PHYS 131 delivered accurate and meaningful data to the ENGR 333 class to aid in the argument for and description of a Calvin solar farm.

Appendix F.1 Figures and Tables

Table F.1: Full Progression to Calculate Deliverables

Name	# of panels	Power rating (W)	Azimuth (deg)	Tilt (deg)	1	2	3	4	5	6	7
Prince Conf Center	459	430	180	adjustable	✓	✓	✓	✓	✓	✓	✓
Devos Comm	632	430	160	adjustable		✓	✓	✓	✓	✓	✓
Hiemenga Hall	722	430	178	adjustable			✓	✓	✓	✓	✓
Hekman Library	925	430	178	adjustable			✓	✓	✓	✓	✓
Lake Dr Entrance	261	720	adjustable	adjustable				✓	✓	✓	✓
Seminary Field	311	720	180	adjustable					✓	✓	✓
Aquatic Center	672	430	178	14.03						✓	✓
Van Noord Arena	834	430	164	10.3							✓

```
mytilt = 30. # Make your choice here for rooftop tilts
Panels.Tilt_deg[1] = mytilt
Panels.Tilt_deg[2] = mytilt
Panels.Tilt_deg[3] = mytilt
Panels.Tilt_deg[4] = mytilt


mytilt = 30. # Make your choice here for ground mounted tilts
myazi = 190. # Make your choice here for ground mounted azimuths.
Panels.Tilt_deg[6] = mytilt
Panels.Tilt_deg[7] = mytilt
Panels.Azi_deg[6] = myazi
```

Figure F.2: Optimization Interface

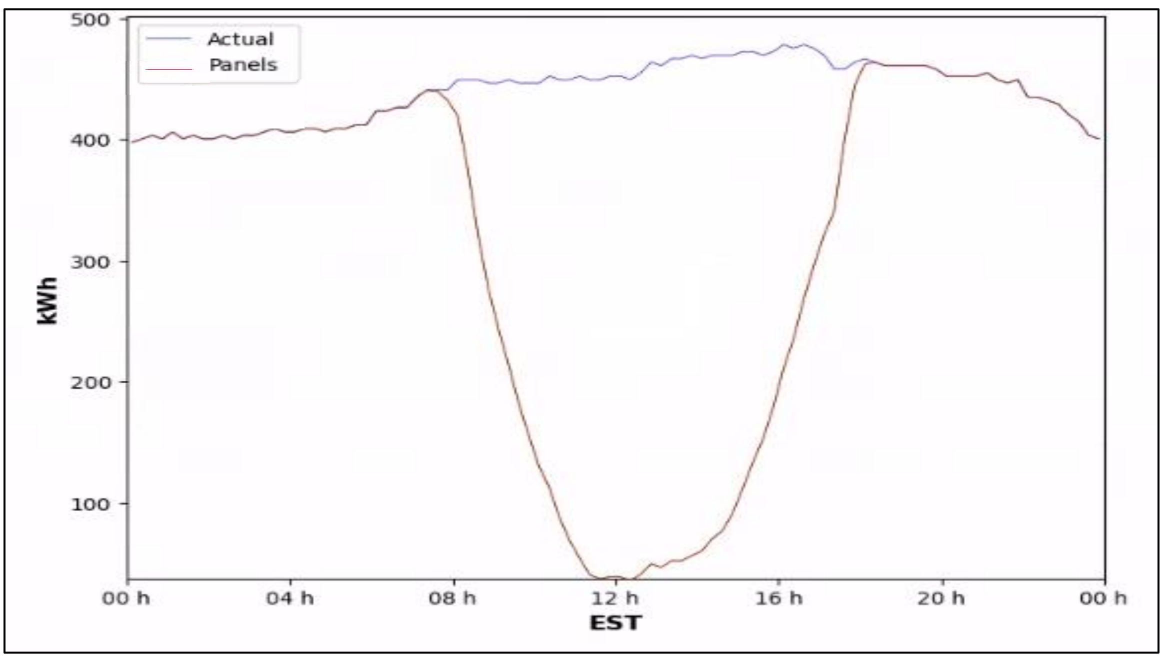


Figure F.3: Calvin Daily Energy Requirements

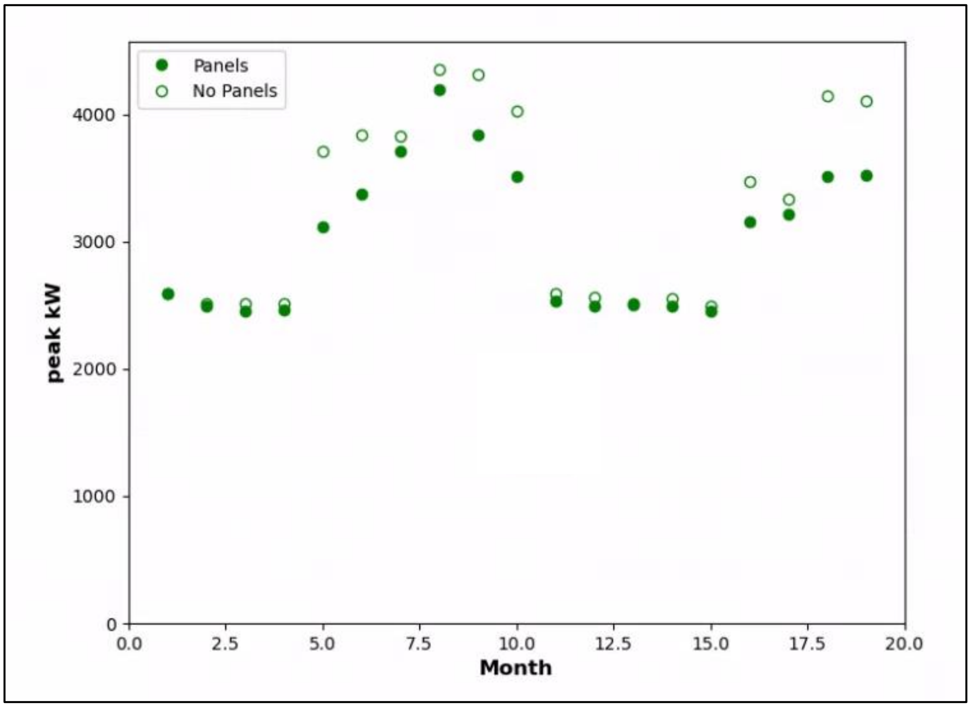


Figure F.4: Peak kW Purchased Per Month

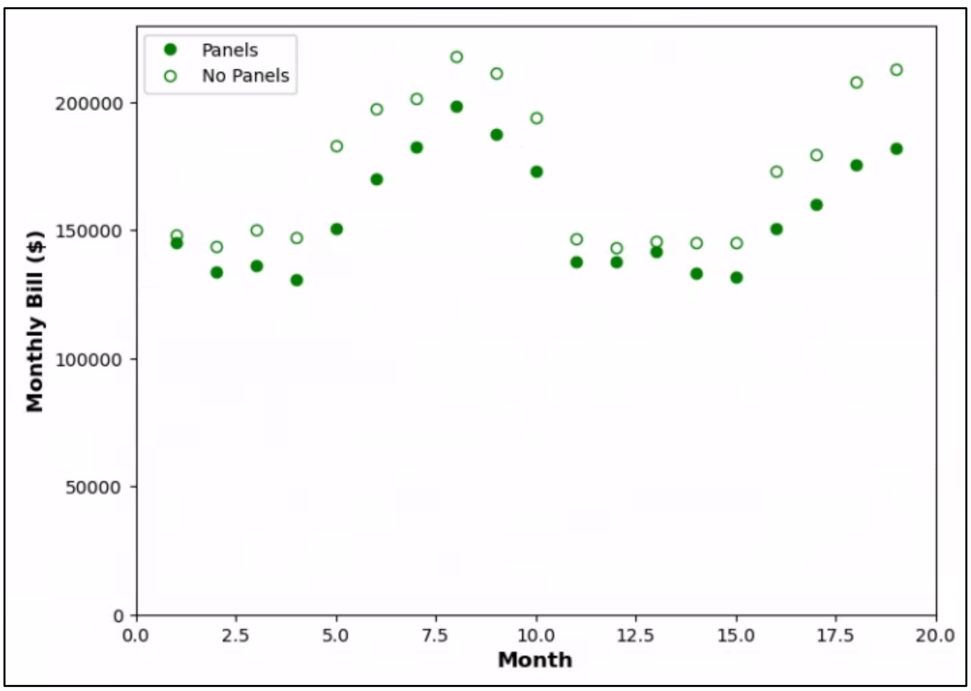


Figure F.5: Calvin’s Monthly Energy Billing

Table F.6: Summary of Final Physics Deliverables

Case	Power [kW]	Saving [Million $]	Saving [GWh]	Loss [GWh]
1	197	0.029	0.228	0.000
2	469	0.061	0.536	0.000
3	1177	0.125	1.355	0.000
4	1365	0.14	1.572	0.000
5	1589	0.159	1.832	0.000
6	1878	0.181	2.155	0.000
7	2237	0.209	2.562	0.001

Appendix G. On-Campus Rooftop Mounting Civil Team

Introduction

The civil class has been asked to analyze the structural capacity of roofs on campus to support numerous solar panel arrays. The only roofs considered contained a significant area facing south to maximize sunlight. Along with the correct direction, these roofs must be without shade for most of the day, requiring little to no tree coverage.

Given these considerations, nine buildings on campus were selected for analysis. The civil class was divided into three groups to conduct the structural analysis for nine roof structures across those nine buildings. Group A, consisting of MJ VanAntwerp, Reid Bentz, Catherine Grissom, and Josh Gage, analyzed the roof structures of the Covenant Fine Arts Center (CFAC) and the Prince Conference Center. Group B consisting of Annalise Holcomb, Daniel Oyer, Josh Lundberg, and Leah Huizenga analyzed the roof structures of North Hall, Business Building, and Devos Communication Center. A final group C consisted of David Bajwa, Garrett Schaaf, and Nate Van Dyke, and analyzed the roof structure of the Aquatic Center, Van Noord Arena, Hekman Library, and Hiemenga Hall.

Results

The only building found to be structurally inadequate for solar panels in its current condition is the CFAC. The CFAC was divided into 5 roof sections in this analysis, and it was found that none can support the additional load in their current state. More detailed professional analysis and additional reinforcement in this building could make it a viable option.

The viable options for solar panel installation are as follows: Devos Communication Center, Business Building, Venema Aquatic Center, Van Noord Arena, Hekman Library, Hiemenga Hall, the circular area of North Hall, and part of the Prince Conference Center. Based on the calculations provided in this report, most of the buildings can support either type of ballasted or mechanically attached solar panels.

It is worth noting that while the Van Noord Arena is a feasible candidate, it is recommended that further analysis of the truss system is conducted with particular attention to the potential placement and load distribution of the photovoltaic system. Hiemenga Hall is another building in which further analysis is recommended, specifically with the type of photovoltaic system. The Prince Conference Center was divided into different roof sections, some which are viable and others which need further investigation due to lack of available documentation.

Overall, 8 out of 9 buildings in this report are able to support the possible additional load of a photovoltaic system

Table G.2: Summary of Findings of Structural Viability

Buildings	Viability
Covenant Fine Arts Center	Not viable for solar panel mounting
Prince Conference Center & Hotel	Conference center viable, hotel unknown
North Hall	Likely viable
Devos Communications Center	Viable for solar panels
Business Building	Viable for solar panels mounted with a ballast system
Venema Aquatic Center	Viable for solar panels
Van Noord Arena	Likely viable
Hekman Library	Viable for solar panels
Hiemenga Hall	Viable for solar panels

Appendix H. Solar Panel Data Sheets

Appendix H.1. CanadianSolar TOPBiHiKu7

CanadianSolar

TOPBiHiKu7

N-type Bifacial TOPCon Technology

690 W ~ 720 W

CS7N-690|695|700|705|710|715|720TB-AG

MORE POWER

720 W — Module power up to 720 W
Module efficiency up to 23.2 %

EXTRA POWER — Up to 85% Power Bifaciality,
more power from the back side

Excellent anti-LeTID & anti-PID performance.
Low power degradation, high energy yield

Lower temperature coefficient (Pmax): -0.29%/°C,
increases energy yield in hot climate

Lower LCOE & system cost

MORE RELIABLE

Tested up to ice ball of 35 mm diameter
according to IEC 61215 standard

Minimizes micro-crack impacts

Heavy snow load up to 5400 Pa,
wind load up to 2400 Pa*

12 Years — **Enhanced Product Warranty on Materials and Workmanship***

30 Years — **Linear Power Performance Warranty***

1st year power degradation no more than 1%
Subsequent annual power degradation no more than 0.4%

*According to the applicable Canadian Solar Limited Warranty Statement.

MANAGEMENT SYSTEM CERTIFICATES*

ISO 9001: 2015 / Quality management system
ISO 14001: 2015 / Standards for environmental management system
ISO 45001: 2018 / International standards for occupational health & safety
IEC 62941: 2019 / Photovoltaic module manufacturing quality system

PRODUCT CERTIFICATES*

IEC 61215 / IEC 61730 / CE / INMETRO / MCS / UKCA / CGC
CEC listed (US California) / FSEC (US Florida)
UL 61730 / IEC 61701 / IEC 62716 / IEC 60068-2-68
UNI 9177 Reaction to Fire: Class 1 / Take-e-way

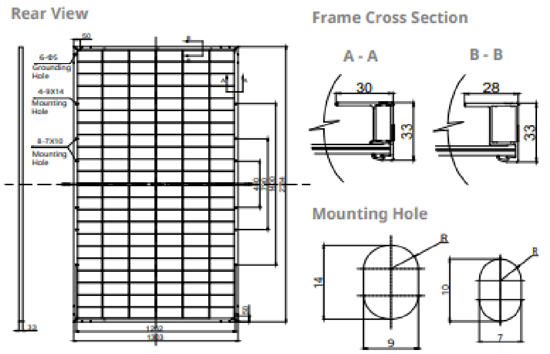
* The specific certificates applicable to different module types and markets will vary, and therefore not all of the certifications listed herein will simultaneously apply to the products you order or use. Please contact your local Canadian Solar sales representative to confirm the specific certificates available for your Product and applicable in the regions in which the products will be used.

CSI Solar Co., Ltd. is committed to providing high quality solar photovoltaic modules, solar energy and battery storage solutions to customers. The company was recognized as the No. 1 module supplier for quality and performance/price ratio in the IHS Module Customer Insight Survey. Over the past 23 years, it has successfully delivered over 125 GW of premium-quality solar modules across the world.

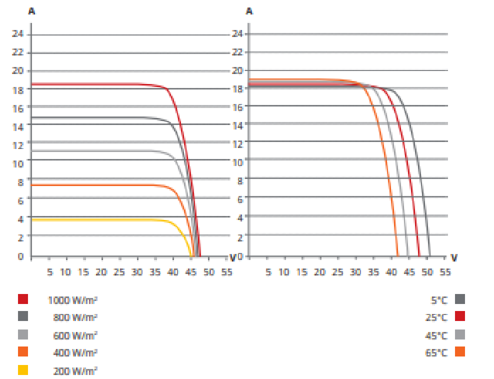
* For detailed information, please refer to the Installation Manual.

CSI Solar Co., Ltd.
199 Lushan Road, SND, Suzhou, Jiangsu, China, 215129, www.csisolar.com, support@csisolar.com

ENGINEERING DRAWING (mm)



CS7N-695TB-AG / I-V CURVES



ELECTRICAL DATA | STC*

		Nominal Max. Power (Pmax)	Opt. Operating Voltage (Vmp)	Opt. Operating Current (Imp)	Open Circuit Voltage (Voc)	Short Circuit Current (Isc)	Module Efficiency
CS7N-690TB-AG		690 W	39.6 V	17.43 A	47.5 V	18.39 A	22.2%
Bifacial Gain**	5%	725 W	39.6 V	18.30 A	47.5 V	19.31 A	23.3%
	10%	759 W	39.6 V	19.17 A	47.5 V	20.23 A	24.4%
	20%	828 W	39.6 V	20.92 A	47.5 V	22.07 A	26.7%
CS7N-695TB-AG		695 W	39.8 V	17.47 A	47.7 V	18.44 A	22.4%
Bifacial Gain**	5%	730 W	39.8 V	18.34 A	47.7 V	19.36 A	23.5%
	10%	765 W	39.8 V	19.22 A	47.7 V	20.28 A	24.6%
	20%	834 W	39.8 V	20.96 A	47.7 V	22.13 A	26.8%
CS7N-700TB-AG		700 W	40.0 V	17.51 A	47.9 V	18.49 A	22.5%
Bifacial Gain**	5%	735 W	40.0 V	18.39 A	47.9 V	19.41 A	23.7%
	10%	770 W	40.0 V	19.26 A	47.9 V	20.34 A	24.8%
	20%	840 W	40.0 V	21.01 A	47.9 V	22.19 A	27.0%
CS7N-705TB-AG		705 W	40.2 V	17.55 A	48.1 V	18.54 A	22.7%
Bifacial Gain**	5%	740 W	40.2 V	18.43 A	48.1 V	19.47 A	23.8%
	10%	776 W	40.2 V	19.31 A	48.1 V	20.39 A	25.0%
	20%	846 W	40.2 V	21.06 A	48.1 V	22.25 A	27.2%
CS7N-710TB-AG		710 W	40.4 V	17.59 A	48.3 V	18.59 A	22.9%
Bifacial Gain**	5%	746 W	40.4 V	18.47 A	48.3 V	19.52 A	24.0%
	10%	781 W	40.4 V	19.35 A	48.3 V	20.45 A	25.1%
	20%	852 W	40.4 V	21.11 A	48.3 V	22.31 A	27.4%
CS7N-715TB-AG		715 W	40.6 V	17.63 A	48.5 V	18.64 A	23.0%
Bifacial Gain**	5%	751 W	40.6 V	18.51 A	48.5 V	19.57 A	24.2%
	10%	787 W	40.6 V	19.39 A	48.5 V	20.50 A	25.3%
	20%	858 W	40.6 V	21.16 A	48.5 V	22.37 A	27.6%
CS7N-720TB-AG		720 W	40.8 V	17.67 A	48.7 V	18.69 A	23.2%
Bifacial Gain**	5%	756 W	40.8 V	18.55 A	48.7 V	19.62 A	24.3%
	10%	792 W	40.8 V	19.44 A	48.7 V	20.56 A	25.5%
	20%	864 W	40.8 V	21.20 A	48.7 V	22.43 A	27.8%

* Under Standard Test Conditions (STC) of irradiance of 1000 W/m², spectrum AM 1.5 and cell temperature of 25°C.
** Bifacial Gain: The additional gain from the back side compared to the power of the front side at the standard test condition. It depends on mounting (structure, height, tilt angle etc.) and albedo of the ground.

ELECTRICAL DATA | NMOT*

	Nominal Max. Power (Pmax)	Opt. Operating Voltage (Vmp)	Opt. Operating Current (Imp)	Open Circuit Voltage (Voc)	Short Circuit Current (Isc)
CS7N-690TB-AG	522 W	37.4 V	13.94 A	45.0 V	14.83 A
CS7N-695TB-AG	526 W	37.6 V	13.97 A	45.2 V	14.87 A
CS7N-700TB-AG	529 W	37.8 V	14.00 A	45.4 V	14.91 A
CS7N-705TB-AG	533 W	38.0 V	14.03 A	45.5 V	14.95 A
CS7N-710TB-AG	537 W	38.2 V	14.06 A	45.7 V	14.99 A
CS7N-715TB-AG	541 W	38.4 V	14.09 A	45.9 V	15.03 A
CS7N-720TB-AG	544 W	38.6 V	14.12 A	46.1 V	15.07 A

* Under Nominal Module Operating Temperature (NMOT), irradiance of 800 W/m² spectrum AM 1.5, ambient temperature 20°C, wind speed 1 m/s.

MECHANICAL DATA

Specification	Data
Cell Type	TOPCon cells
Cell Arrangement	132 [2 x (11 x 6)]
Dimensions	2384 × 1303 × 33 mm (93.9 × 51.3 × 1.30 in)
Weight	37.8 kg (83.3 lbs)
Front Glass	2.0 mm heat strengthened glass with anti-reflective coating
Back Glass	2.0 mm heat strengthened glass
Frame	Anodized aluminium alloy
J-Box	IP68, 3 bypass diodes
Cable	4.0 mm² (IEC), 12 AWG (UL)
Cable Length (Including Connector)	360 mm (14.2 in) (+) / 200 mm (7.9 in) (-) or customized length*
Connector	T6 or MC4-EVO2 or MC4-EVO2A
Per Pallet	33 pieces
Per Container (40' HQ)	594 pieces or 495 pieces (only for US & Canada)

* For detailed information, please contact your local Canadian Solar sales and technical representatives.

ELECTRICAL DATA

Operating Temperature	-40°C ~ +85°C
Max. System Voltage	1500 V (IEC/UL)
Module Fire Performance	TYPE 29 (UL 61730) or CLASS C (IEC61730)
Max. Series Fuse Rating	35 A
Protection Class	Class II
Power Tolerance	0 ~ + 10 W
Power Bifaciality*	80 %

* Power Bifaciality = $Pmax_{rear}$ / $Pmax_{front}$, both $Pmax_{rear}$ and $Pmax_{front}$ are tested under STC, Bifaciality Tolerance: ± 5 %

TEMPERATURE CHARACTERISTICS

Specification	Data
Temperature Coefficient (Pmax)	-0.29 % / °C
Temperature Coefficient (Voc)	-0.25 % / °C
Temperature Coefficient (Isc)	0.05 % / °C
Nominal Module Operating Temperature	41 ± 3°C

PARTNER SECTION

* The specifications and key features contained in this datasheet may deviate slightly from our actual products due to the on-going innovation and product enhancement. CSI Solar Co., Ltd. reserves the right to make necessary adjustment to the information described herein at any time without further notice.
Please be kindly advised that PV modules should be handled and installed by qualified people who have professional skills and please carefully read the safety and installation instructions before using our PV modules.

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Appendix H.2. CanadianSolar TOPHiKu6 Datasheet.

CanadianSolar

TOPHiKu6

N-type TOPCon Technology

425 W ~ 450 W

CS6R-425|430|435|440|445|450T

MORE POWER

Module power up to 450 W
Module efficiency up to 23.0 %

Excellent anti-LeTID & anti-PID performance.
Low power degradation, high energy yield

Lower temperature coefficient (Pmax): -0.29%/°C, increases energy yield in hot climate

Lower LCOE & system cost

MORE RELIABLE

Tested up to ice ball of 45 mm diameter according to IEC 61215 standard

Minimizes micro-crack impacts

Heavy snow load up to 5400 Pa, wind load up to 2400 Pa*

*Black frame product can be provided upon request.

12 Years **Enhanced Product Warranty on Materials and Workmanship***

30 Years **Linear Power Performance Warranty***

1st year power degradation no more than 1%
Subsequent annual power degradation no more than 0.4%

*According to the applicable Canadian Solar Limited Warranty Statement.

MANAGEMENT SYSTEM CERTIFICATES*

ISO 9001: 2015 / Quality management system
ISO 14001: 2015 / Standards for environmental management system
ISO 45001: 2018 / International standards for occupational health & safety
IEC 62941: 2019 / Photovoltaic module manufacturing quality system

PRODUCT CERTIFICATES*

IEC 61215 / IEC 61730 / CE / INMETRO / MCS / UKCA / CGC
UL 61730 / IEC 61701 / IEC 62716 / IEC 60068-2-68
UNI 9177 Reaction to Fire: Class 1 / Take-e-way

* The specific certificates applicable to different module types and markets will vary, and therefore not all of the certifications listed herein will simultaneously apply to the products you order or use. Please contact your local Canadian Solar sales representative to confirm the specific certificates available for your Product and applicable in the regions in which the products will be used.

CSI Solar Co., Ltd. is committed to providing high quality solar photovoltaic modules, solar energy and battery storage solutions to customers. The company was recognized as the No. 1 module supplier for quality and performance/price ratio in the IHS Module Customer Insight Survey. Over the past 23 years, it has successfully delivered over 125 GW of premium-quality solar modules across the world.

* For detailed information, please refer to the Installation Manual.

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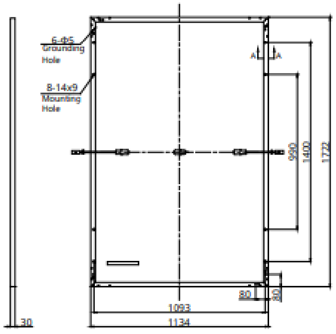
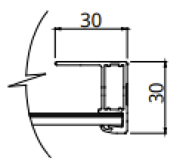
ENGINEERING DRAWING (mm)

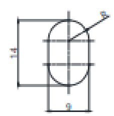
Rear View



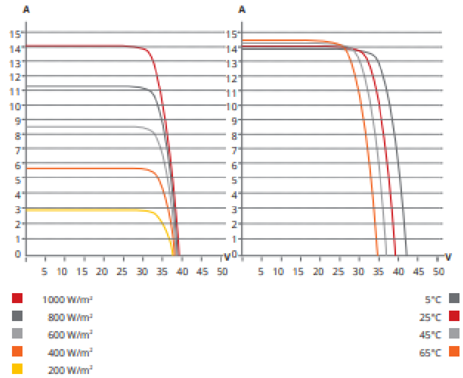
Frame Cross Section A-A



Mounting Hole



CS6R-440T / I-V CURVES



ELECTRICAL DATA | STC*

CS6R	425T	430T	435T	440T	445T	450T
Nominal Max. Power (Pmax)	425 W	430 W	435 W	440 W	445 W	450 W
Opt. Operating Voltage (Vmp)	31.8 V	32.0 V	32.2 V	32.4 V	32.6 V	32.8 V
Opt. Operating Current (Imp)	13.37 A	13.44 A	13.51 A	13.59 A	13.66 A	13.72 A
Open Circuit Voltage (Voc)	38.8 V	39.0 V	39.2 V	39.4 V	39.6 V	39.8 V
Short Circuit Current (Isc)	13.78 A	13.86 A	13.94 A	14.01 A	14.09 A	14.16 A
Module Efficiency	21.8%	22.0%	22.3%	22.5%	22.8%	23.0%
Operating Temperature	-40°C ~ +85°C					
Max. System Voltage	1500V (IEC/UL) or 1000V (IEC/UL)					
Module Fire Performance	TYPE 1 (UL 61730 1500V) or TYPE 2 (UL 61730 1000V) or CLASS C (IEC 61730)					
Max. Series Fuse Rating	25 A					
Protection Class	Class II					
Power Tolerance	0 ~ + 10 W					

* Under Standard Test Conditions (STC) of irradiance of 1000 W/m², spectrum AM 1.5 and cell temperature of 25°C.

ELECTRICAL DATA | NMOT*

CS6R	425T	430T	435T	440T	445T	450T
Nominal Max. Power (Pmax)	321 W	325 W	329 W	333 W	337 W	340 W
Opt. Operating Voltage (Vmp)	30.1 V	30.3 V	30.4 V	30.6 V	30.8 V	31.0 V
Opt. Operating Current (Imp)	10.69 A	10.75 A	10.81 A	10.87 A	10.92 A	10.98 A
Open Circuit Voltage (Voc)	36.7 V	36.9 V	37.1 V	37.3 V	37.5 V	37.7 V
Short Circuit Current (Isc)	11.11 A	11.18 A	11.24 A	11.30 A	11.36 A	11.42 A

* Under Nominal Module Operating Temperature (NMOT), irradiance of 800 W/m² spectrum AM 1.5, ambient temperature 20°C, wind speed 1 m/s.

MECHANICAL DATA

Specification	Data
Cell Type	TOPCon cells
Cell Arrangement	108 [2 X (9 X 6)]
Dimensions	1722 × 1134 × 30 mm (67.8 × 44.6 × 1.18 in)
Weight	21.3 kg (47.0 lbs)
Front Cover	3.2 mm tempered glass with anti-reflective coating
Frame	Anodized aluminium alloy,
J-Box	IP68, 3 bypass diodes
Cable	4 mm² (IEC), 12 AWG (UL)
Connector	T6 or MC4 or MC4-EVO2 or MC4-EVO2A
Cable Length (Including Connector)	Portrait: 300 mm (11.8 in) (+) / 200 mm (7.9 in) (-); landscape: 1100 mm (43.3 in)*
Per Pallet	35 pieces
Per Container (40' HQ)	910 pieces or 840 pieces (only for US & Canada)

* For detailed information, please contact your local Canadian Solar sales and technical representatives.

TEMPERATURE CHARACTERISTICS

Specification	Data
Temperature Coefficient (Pmax)	-0.29 % / °C
Temperature Coefficient (Voc)	-0.25 % / °C
Temperature Coefficient (Isc)	0.05 % / °C
Nominal Module Operating Temperature	41 ± 3°C

PARTNER SECTION

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