

Light Work

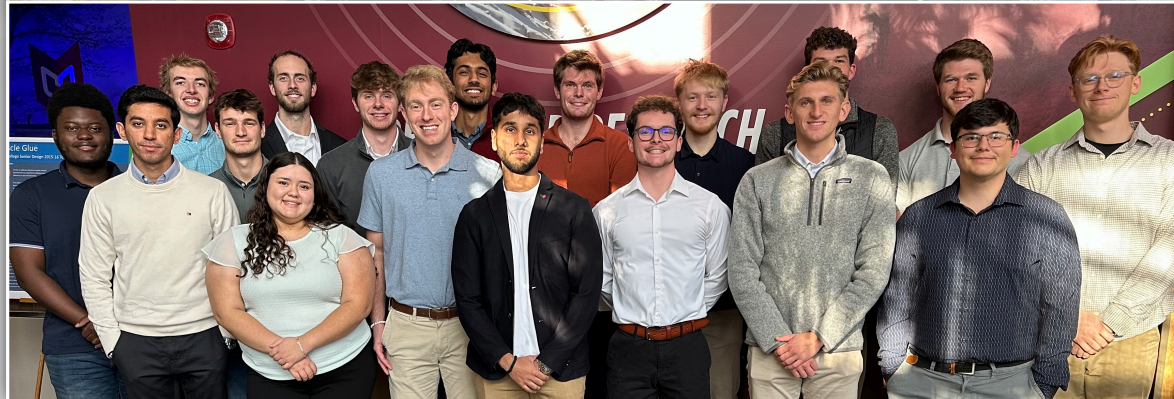
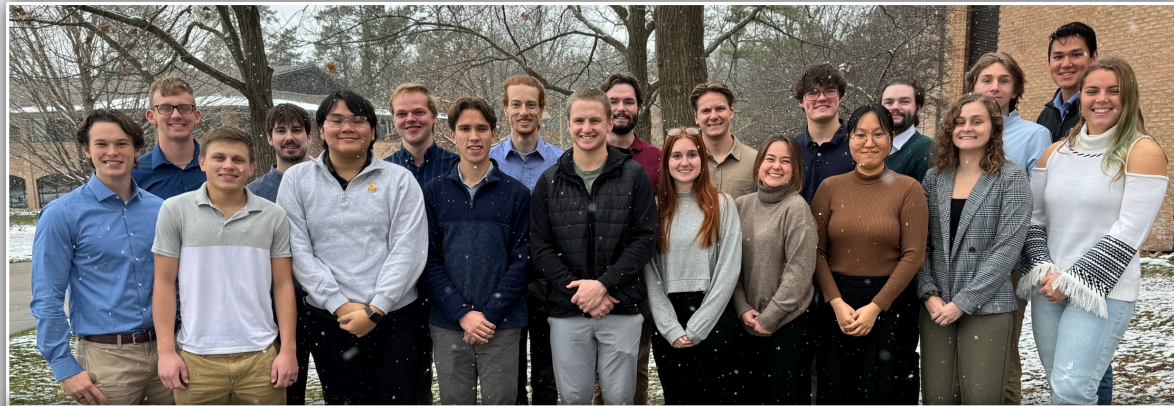
Calvin's Potential Solar Farm

10 December 2024

Brandon Eenigenburg, Aiden Ehmann,
Soren Thiemann, Kai Zwarg



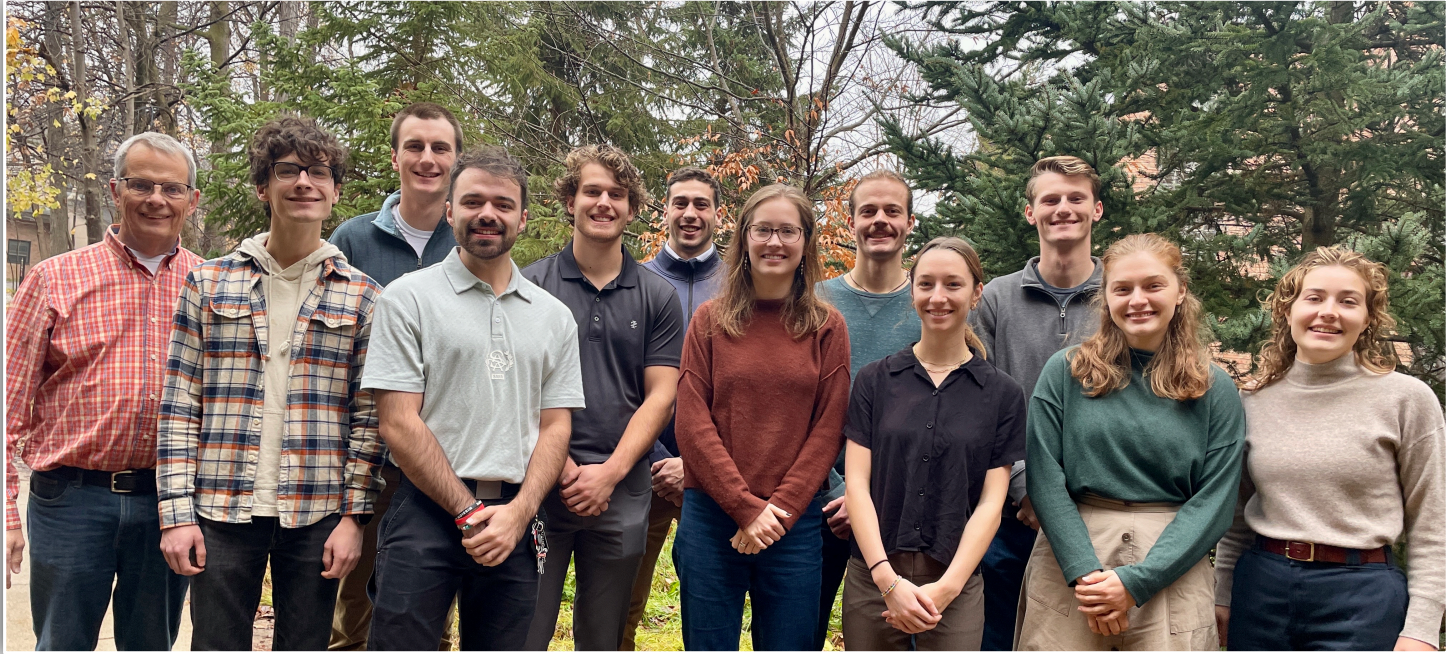
Thermo Team



Physics Team



Civil Team



The Problem



Chimes

Calvin commits to carbon neutrality by 2057

Rae Gernant, Head Copy Editor | December 8, 2017

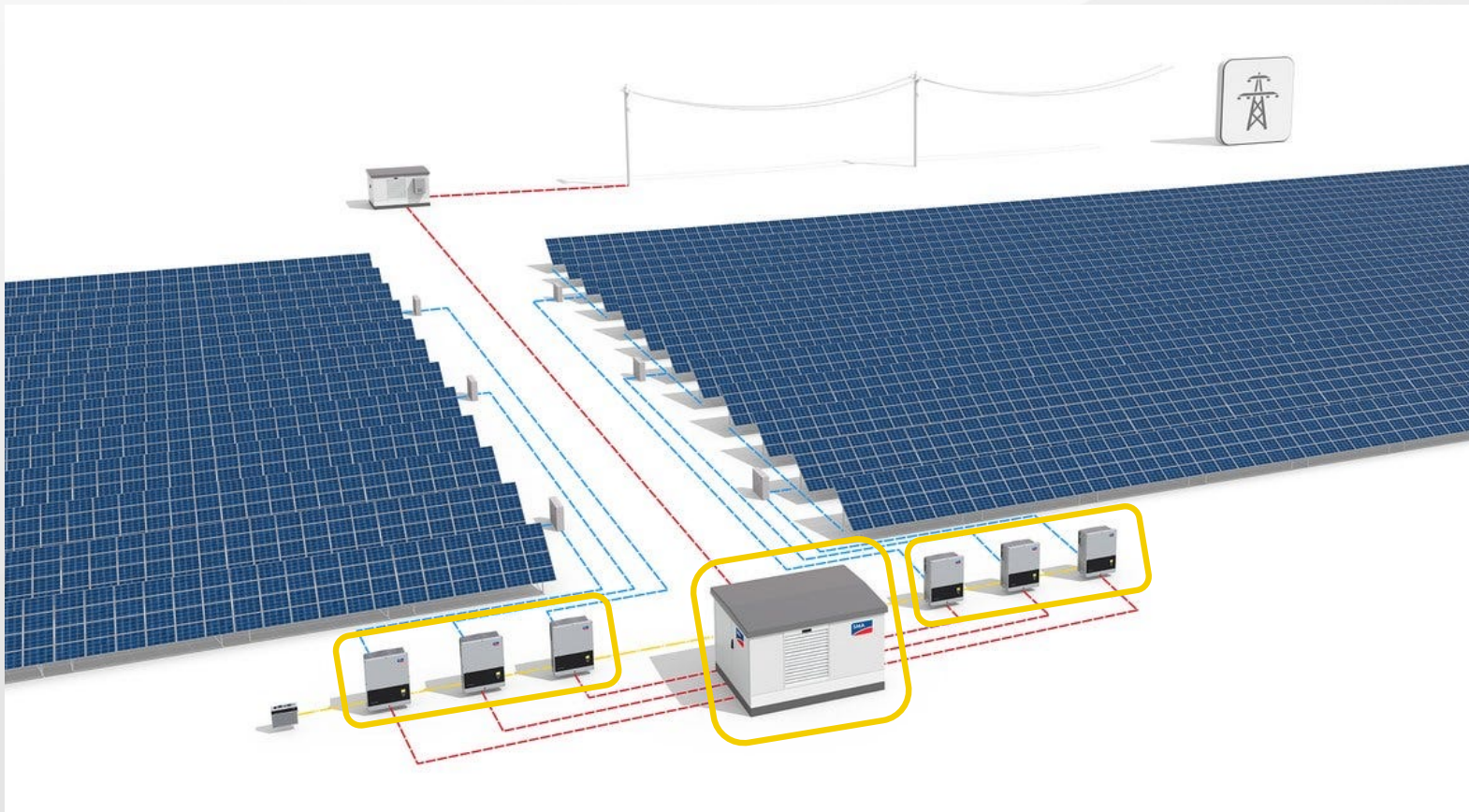


Le Roy signing the Second Nature Climate Commitment. Photo by Hannah Butler.

<https://calvinchimes.org/2017/12/08/calvin-commits-to-carbon-neutrality-by-2057/>



How does Solar work?



What should be the design of Calvin's Solar Farm?



Financials of Higher Education

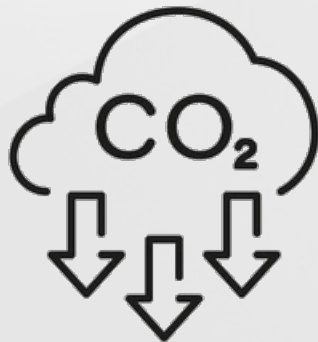
Client: Dirk Pruis, CFO of Calvin University



Defining Success

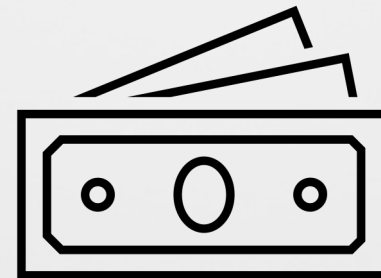
Reduction of CO2 Emissions

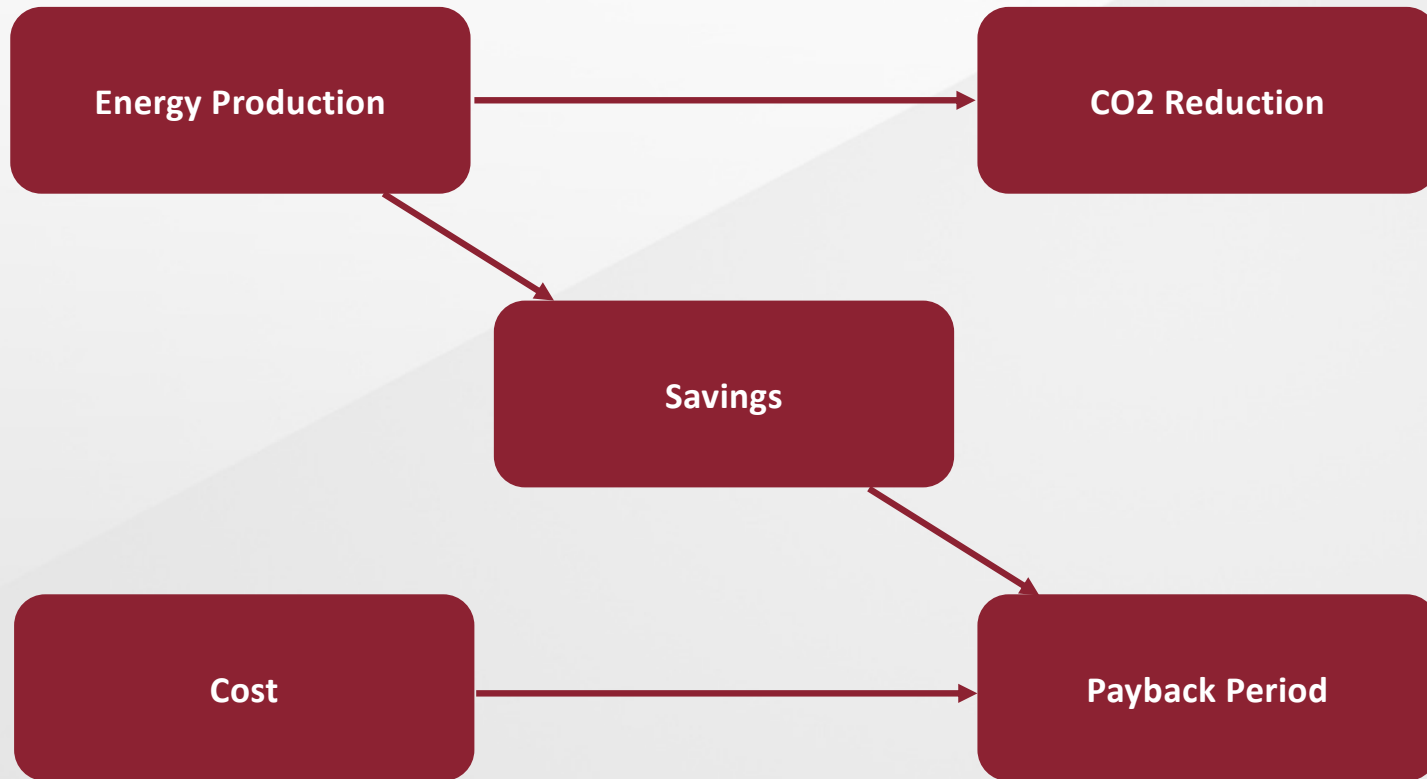
- % CO2 Reduction

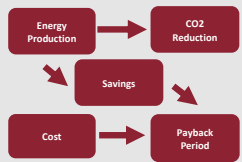


Financial Viability

- Return on Investment (ROI)
- Internal Rate of Return (IRR)
- Payback Period



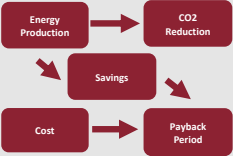




Case Study

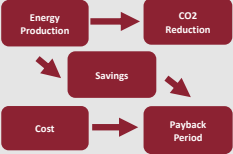
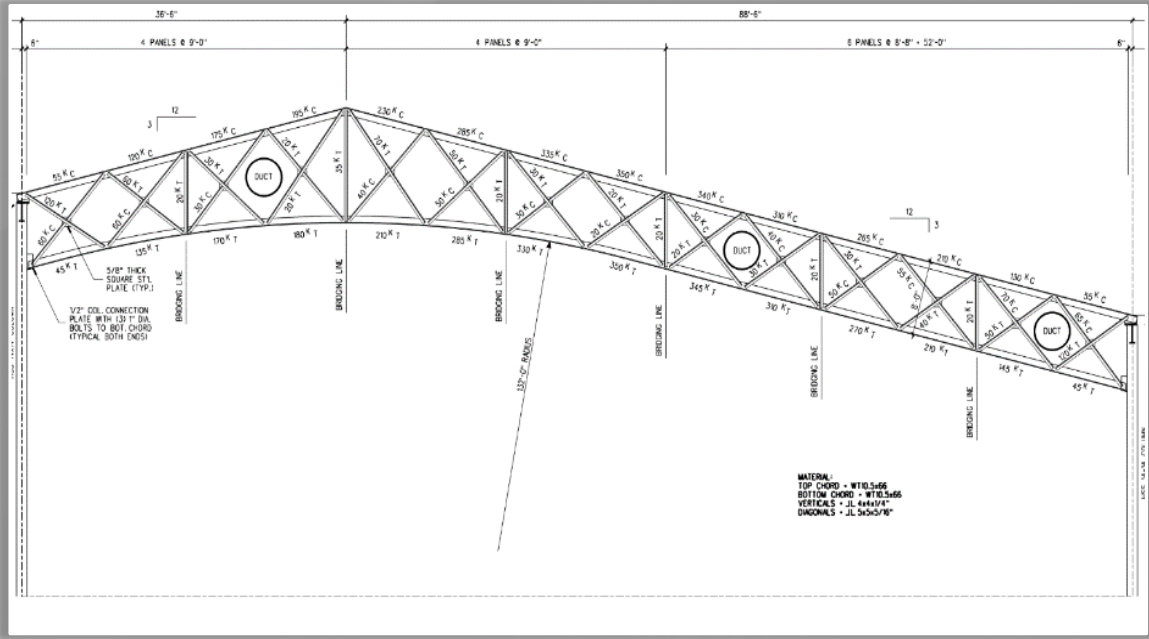


Design - Venema Aquatic Center



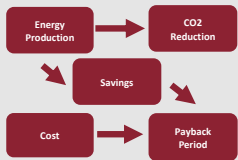
Design - Venema Aquatic Center

- Structural
 - Civil Team



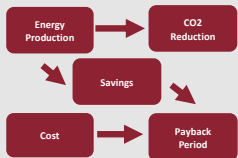
Design - Venema Aquatic Center

- Structural
 - Civil Team
- 672 Panels
 - Silfab 430QD
 - 290 kW System Power



Design - Venema Aquatic Center

- Structural
 - Civil Team
- 672 Panels
 - Silfab 430QD
 - 290 kW System Power
- Mounting Type
 - Rooftop Slanted

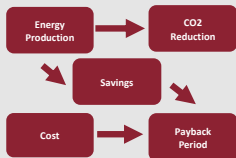


Design - Venema Aquatic Center

- Structural
 - Civil Team
- 672 Panels
 - Silfab 430QD
 - 290 kW System Power
- Mounting Type
 - Rooftop Slanted
- 4 Inverters
 - Solis 75 kW Three Phase

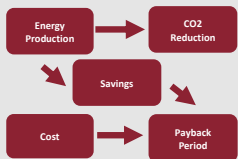
Solis-(75-100)K-5G-US

Solis Three Phase US Inverters



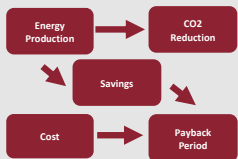
Design - Venema Aquatic Center

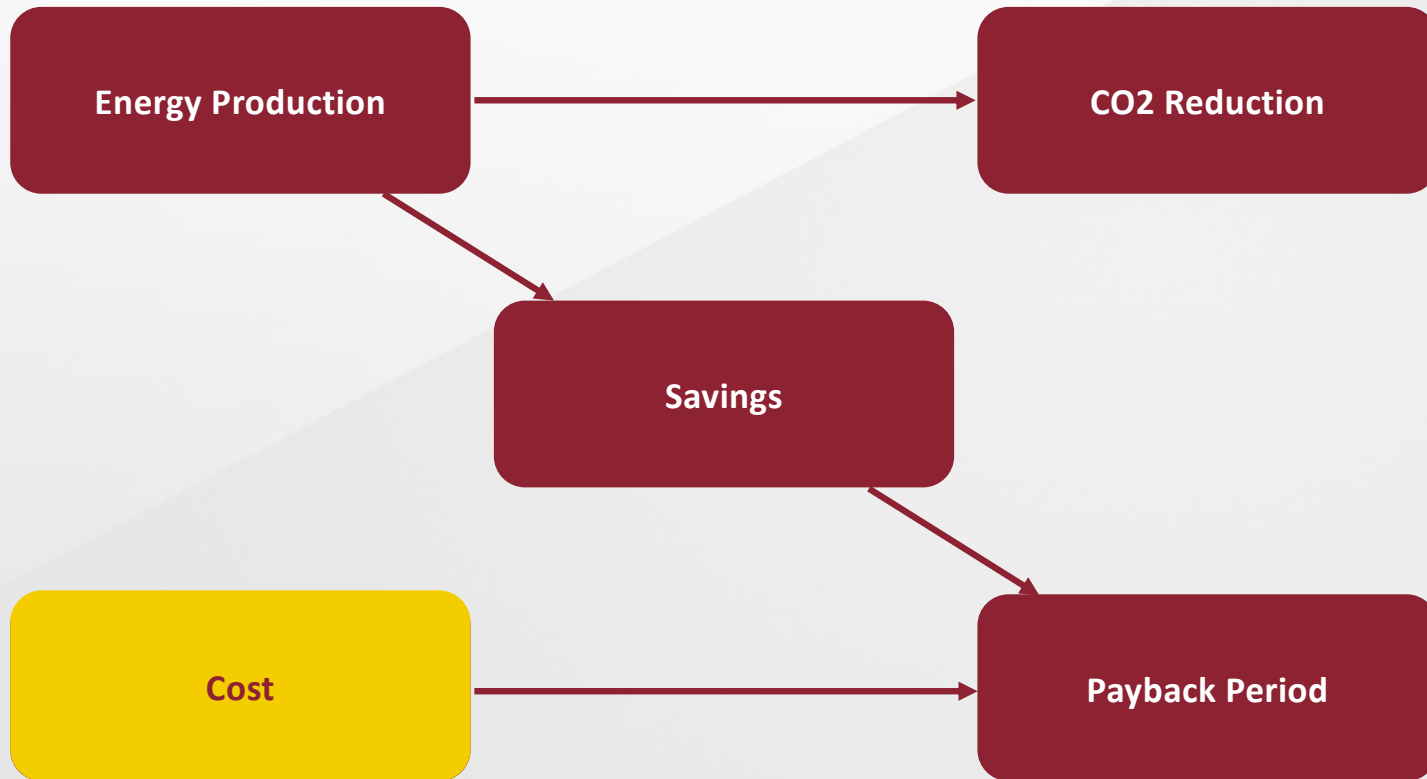
- Structural
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Design - Venema Aquatic Center

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- Transformers





[Redacted]

[Redacted]

[Redacted]

[Redacted]

Quote

Date	Quote #
11/22/2024	QU-145614

Bill To

[Redacted]

[Redacted]

[Redacted]

Ship To

[Redacted]

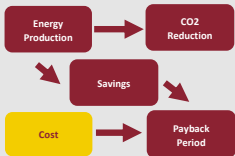
[Redacted]

[Redacted]

Exp. Ship Date 11/22/2024
 30 day Price Ex. 12/6/2024
 Terms Net 30
 Project Name Silfab 430's
 Outside Sales Rep [Redacted]
 Shipping Expense MFR Pays Freight for Drop-Ship
 Shipping Method Best Method
 Ship Blind No
 Lift Gate Required No
 Delivery Appt. Required No
 Residential Delivery No

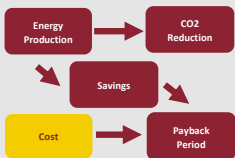
Item	Location	Description	\$/W	Quantity	Price	Amount
SIL-430-QD	Drop ship	Silfab 430w QD mono-PERC module; 108 half cells, black frame, black backsheet, 53.1 in, ø 0.22 in (12 AWG), MC4 from Staubli	[Redacted]	[Redacted]	[Redacted]	[Redacted]
SIL-430-QD-DCA	Drop ship	Silfab 430w QD mono-PERC module; 108 half cells, black frame, black backsheet, 53.1 in, ø 0.22 in (12 AWG), MC4 from Staubli. With USA sourced frame & back sheet. This item includes domestic content and if used in accordance to the provisions set forth by the IRS, may qualify the taxpayer for a Domestic Content Bonus Credit.	[Redacted]	[Redacted]	[Redacted]	[Redacted]

Subtotal	[Redacted]
Shipping Cost	\$0.00
Discount Total	
Tax Total (-Not Taxable-)	\$0.00
Total Amount	[Redacted]



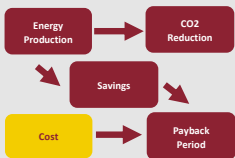
Costs – Venema Aquatic Center

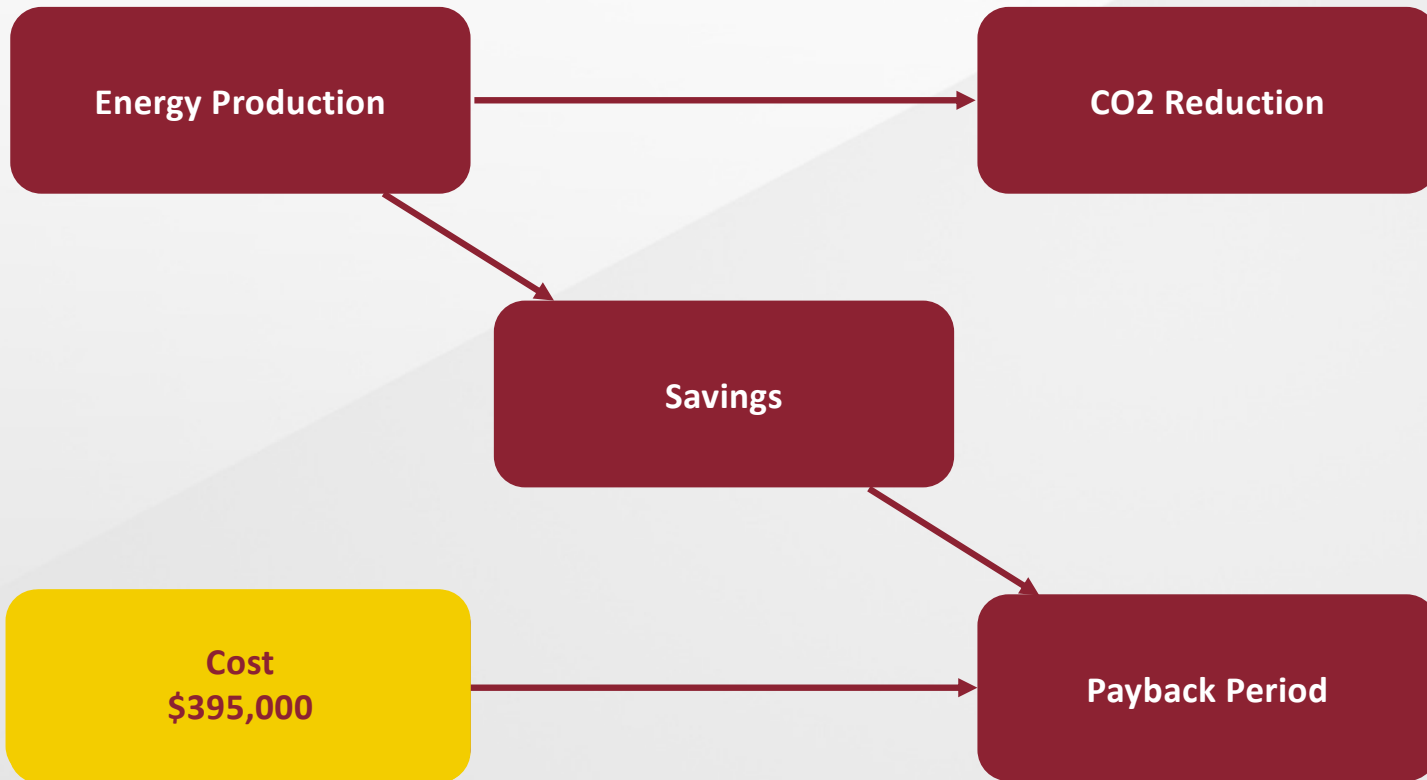
- **Total Initial Investment**
 - **\$395,000** for whole system
 - **\$206,000** in Equipment
 - **\$189,000** in Installation
- **Annual Costs**
 - **\$6,000 / yr**

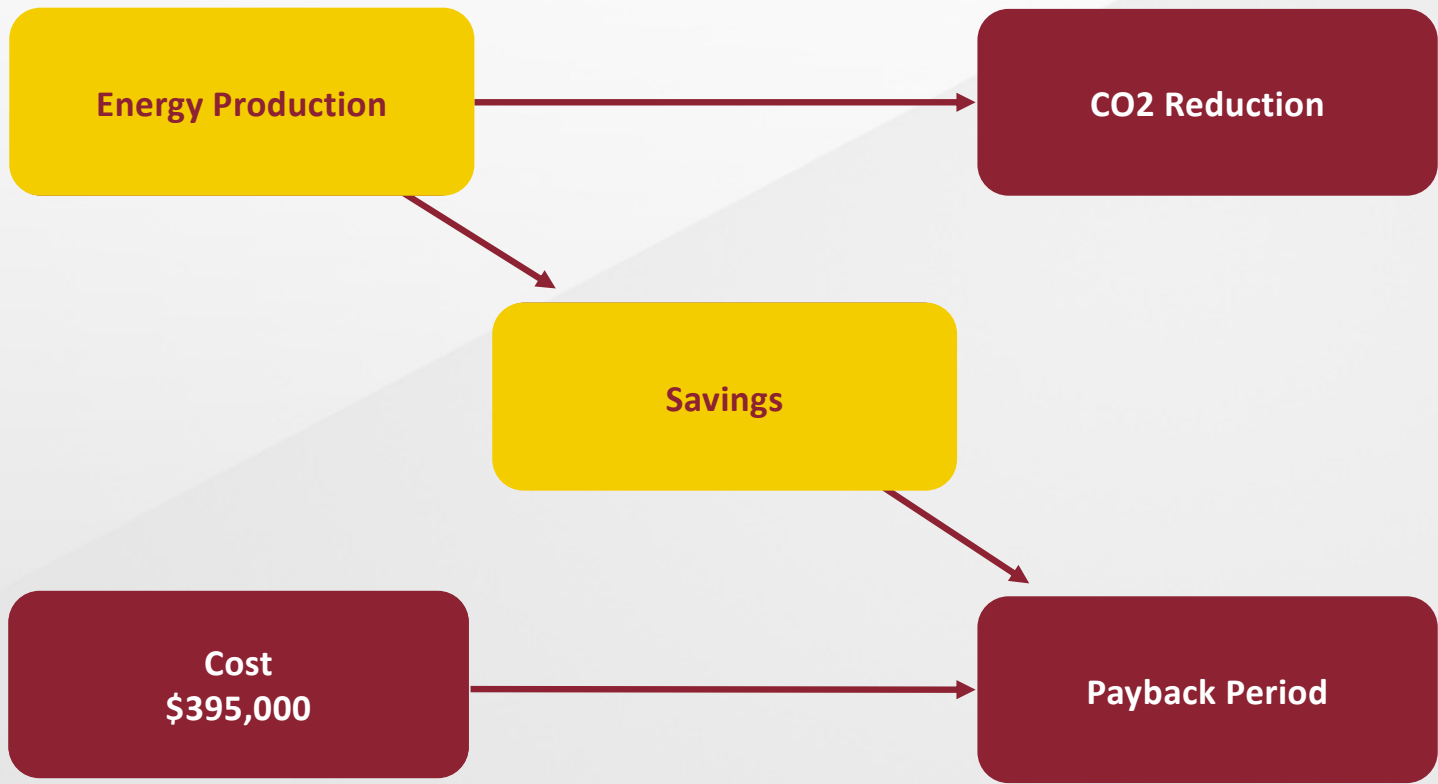


Costs – Venema Aquatic Center

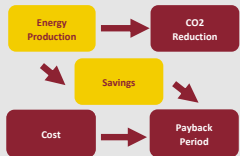
- **\$206,000 in Equipment**
 - **\$113,000** for 672 Panels
 - **\$75,000** for Racking cost
 - **\$18,000** for 4 Inverters
- **\$189,000 in Installation**
 - **\$145,000** Structure Installation and Construction
 - **\$44,000** Installation and tie into Grid



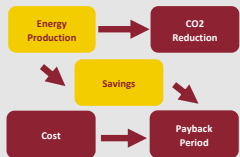
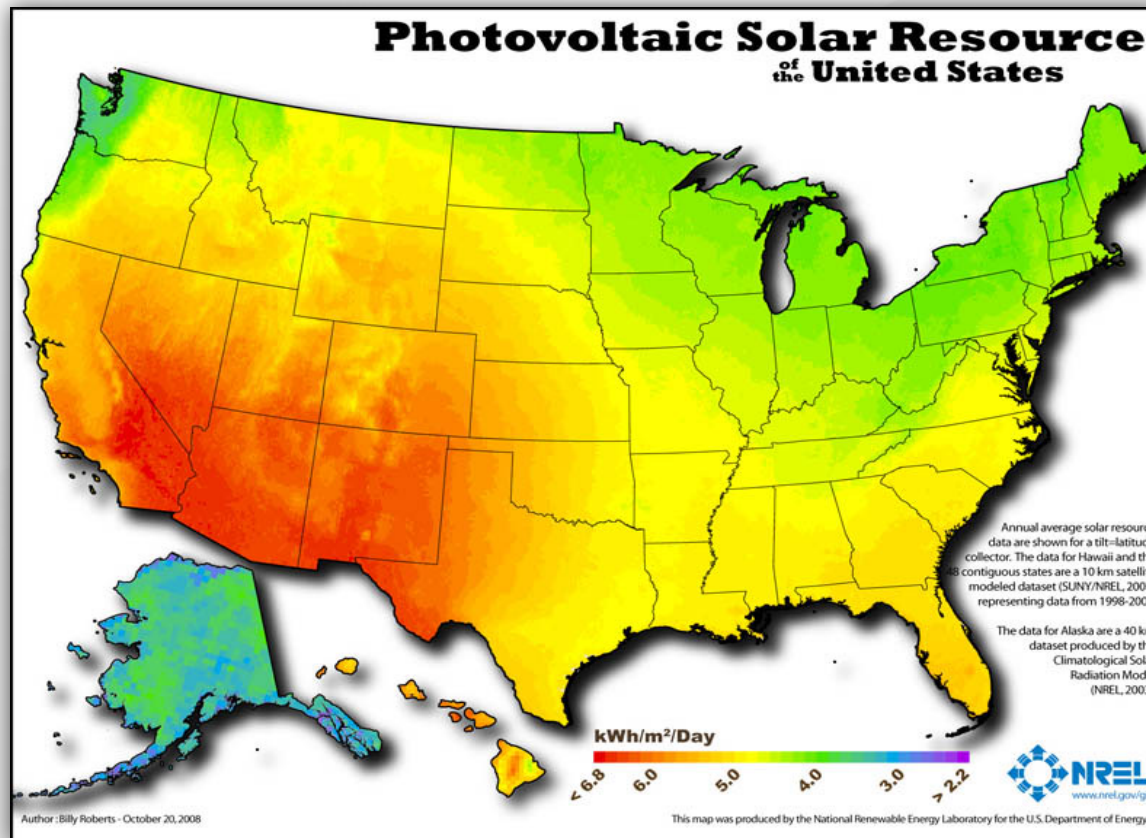




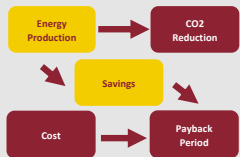
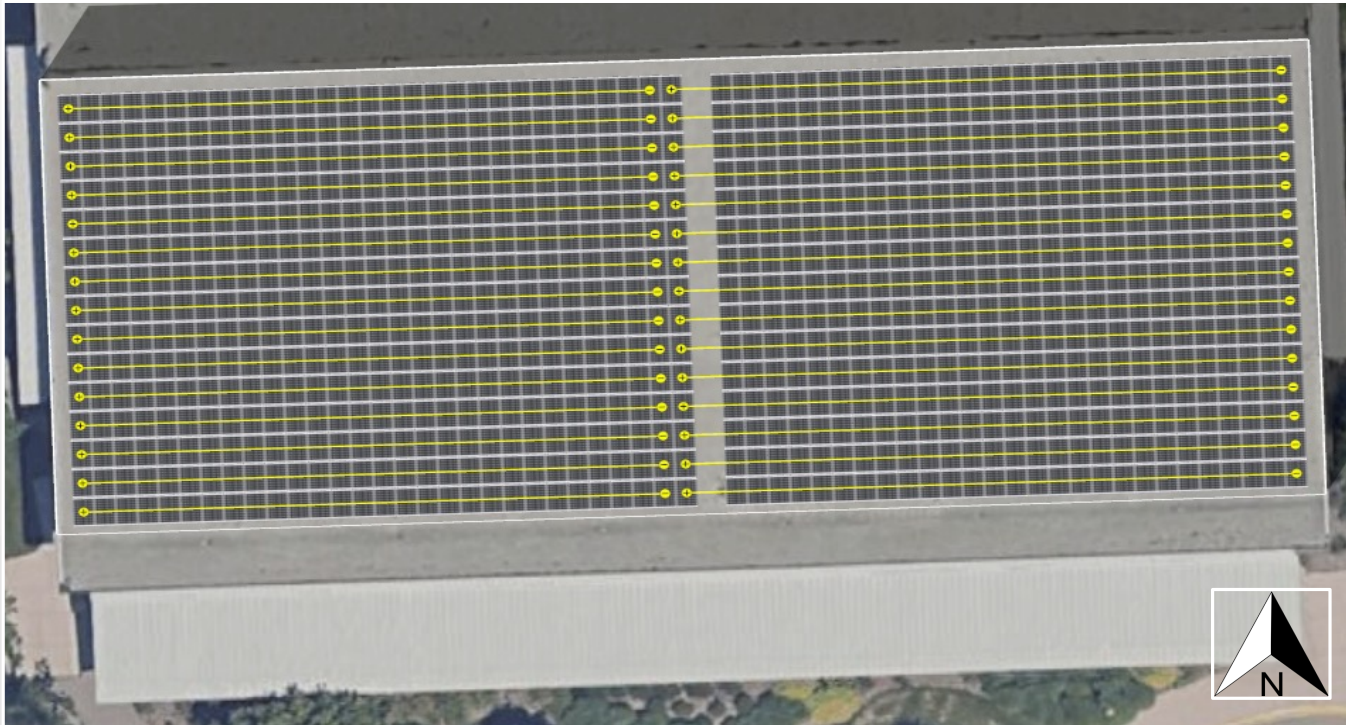
Physics Team



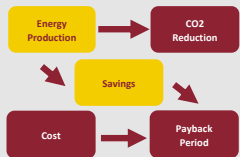
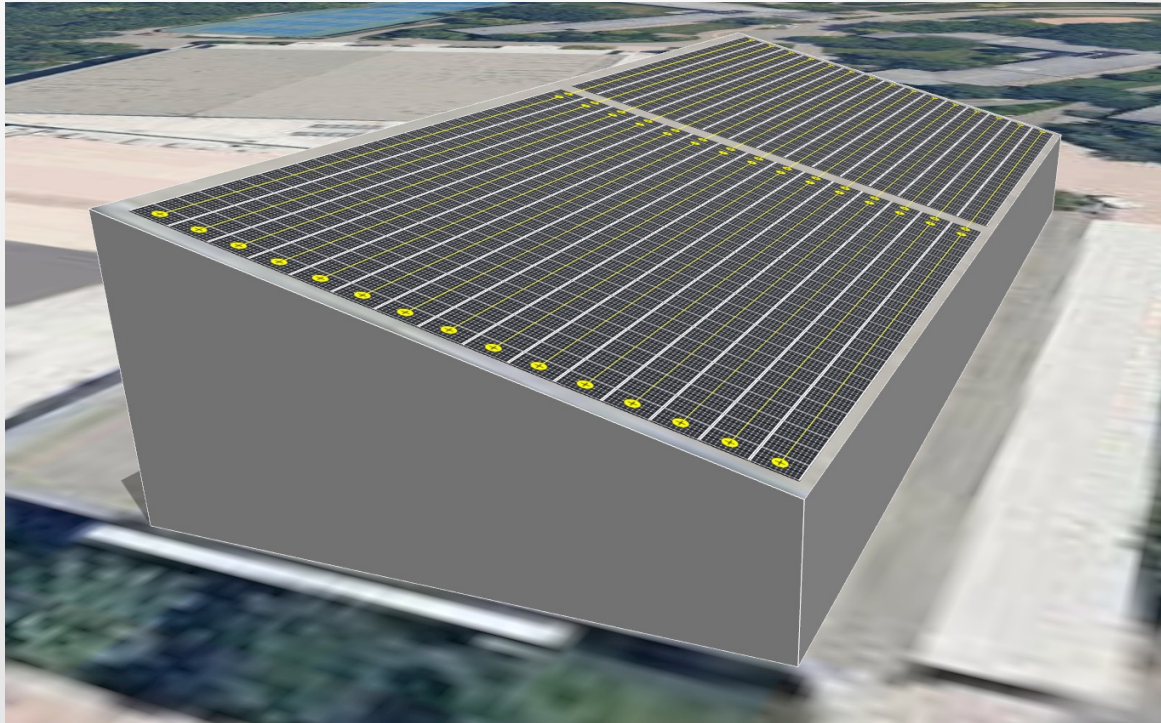
PHYS 131 – Irradiance



PHYS 131 - Azimuth



PHYS 131 - Tilt

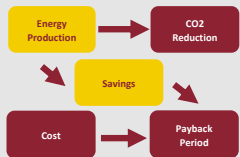


Physics 131

PHYS 131 Question:

Given data for solar farm designs,

- A) Determine optimal tilt and azimuth angles
- B) Calculate power production
- C) Calculate savings in Calvin's electrical billing



Physics 131

ENGR Data

- Number of Panels
- Power Rating
- Tilt & Azimuth
- Adjustable panels

Sunlight Data

- Sun Position

Weather Model

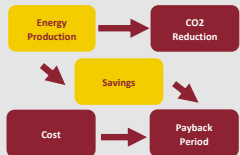
- Real production from local panels

Consumers Energy

- 15-minute segments of Calvin's Energy Bill

Solar Code

- Optimal Tilt & Azimuth
- Power Production
- Savings



Physics 131

ENGR Data

- Number of Panels
- Power Rating
- Tilt & Azimuth
- Adjustable panels

Sunlight Data

- Sun Position

Weather Model

- Real production from local panels

Consumers Energy

- 15-minute segments of Calvin's Energy Bill

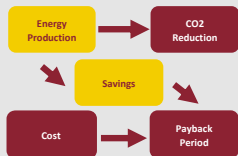
Solar Code

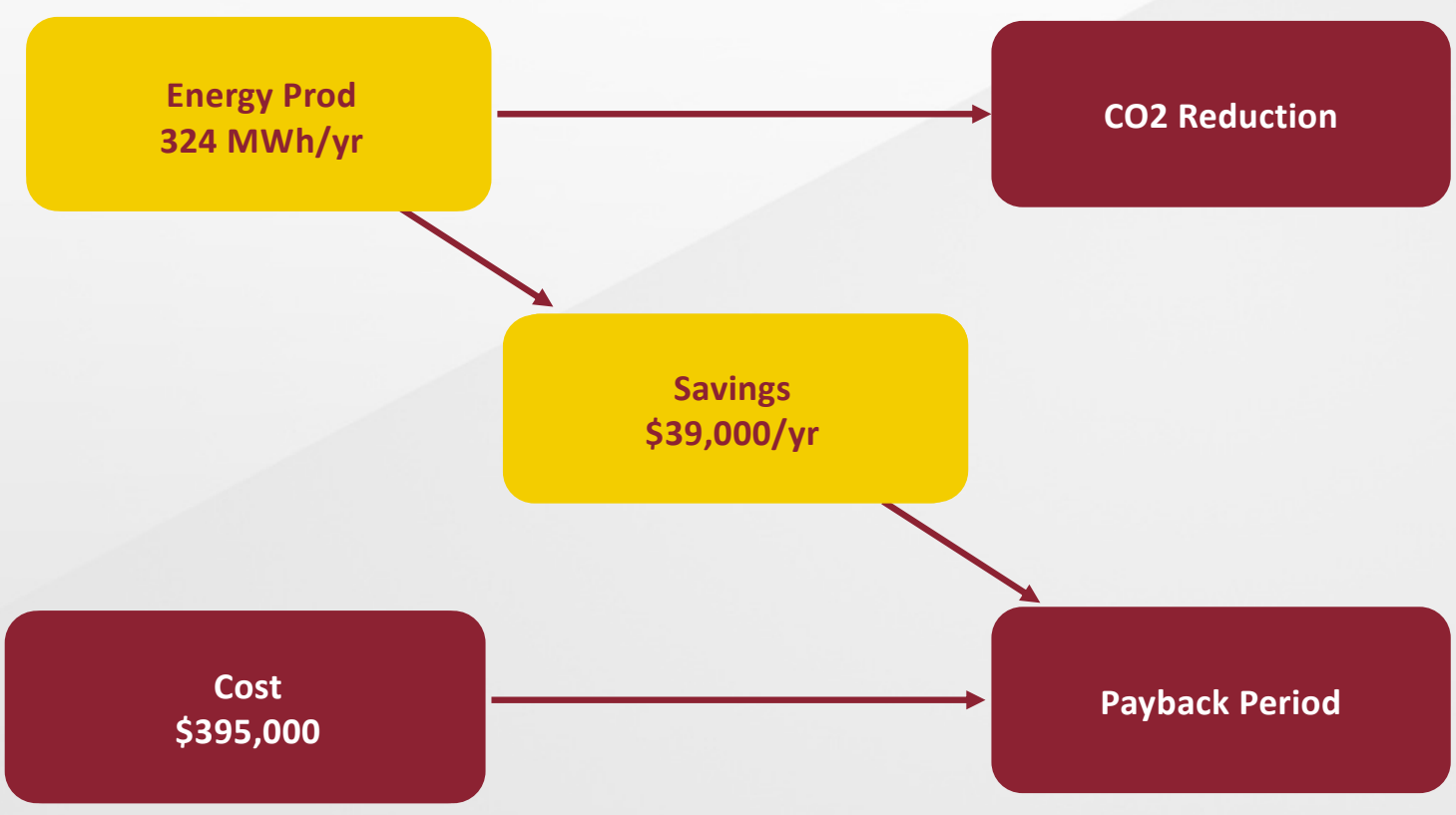
- Optimal Tilt & Azimuth
- Power Production
- Savings

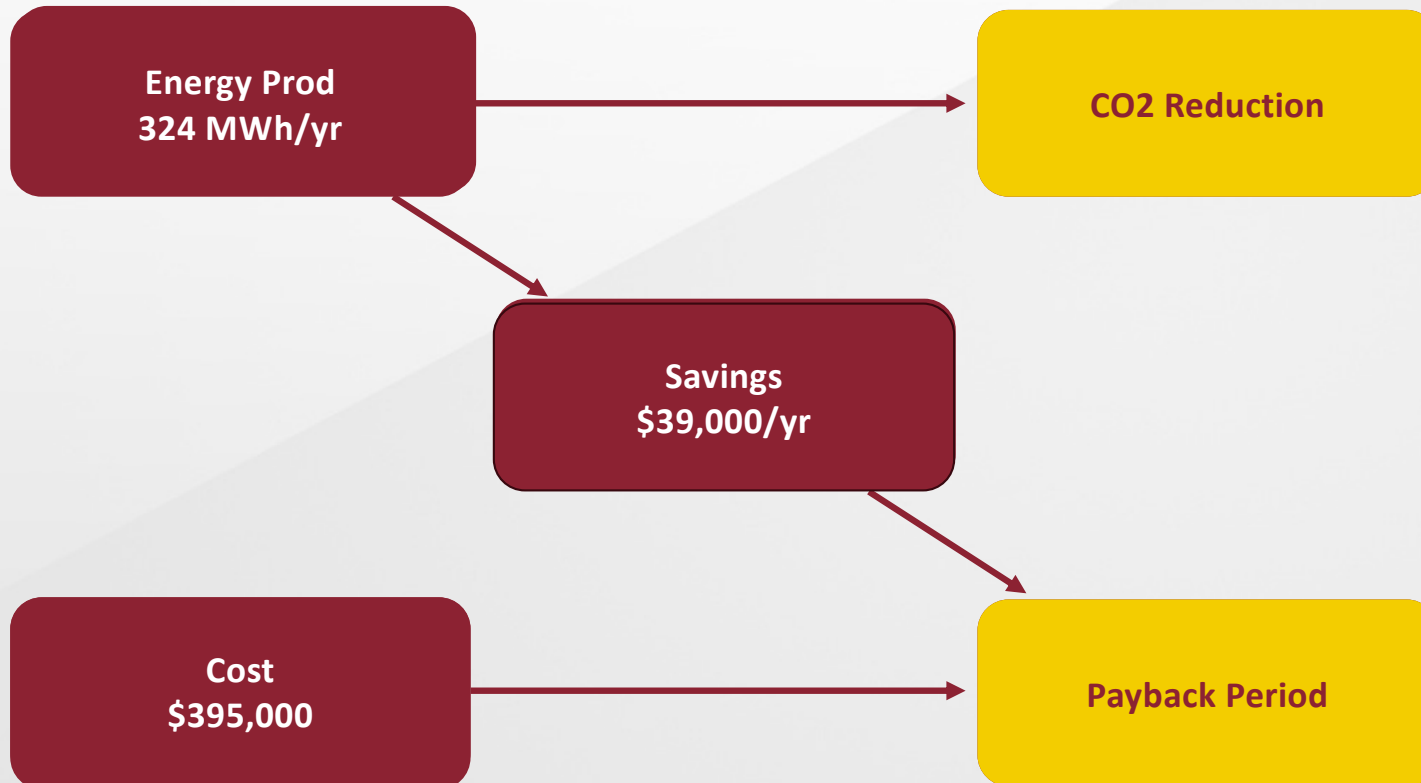


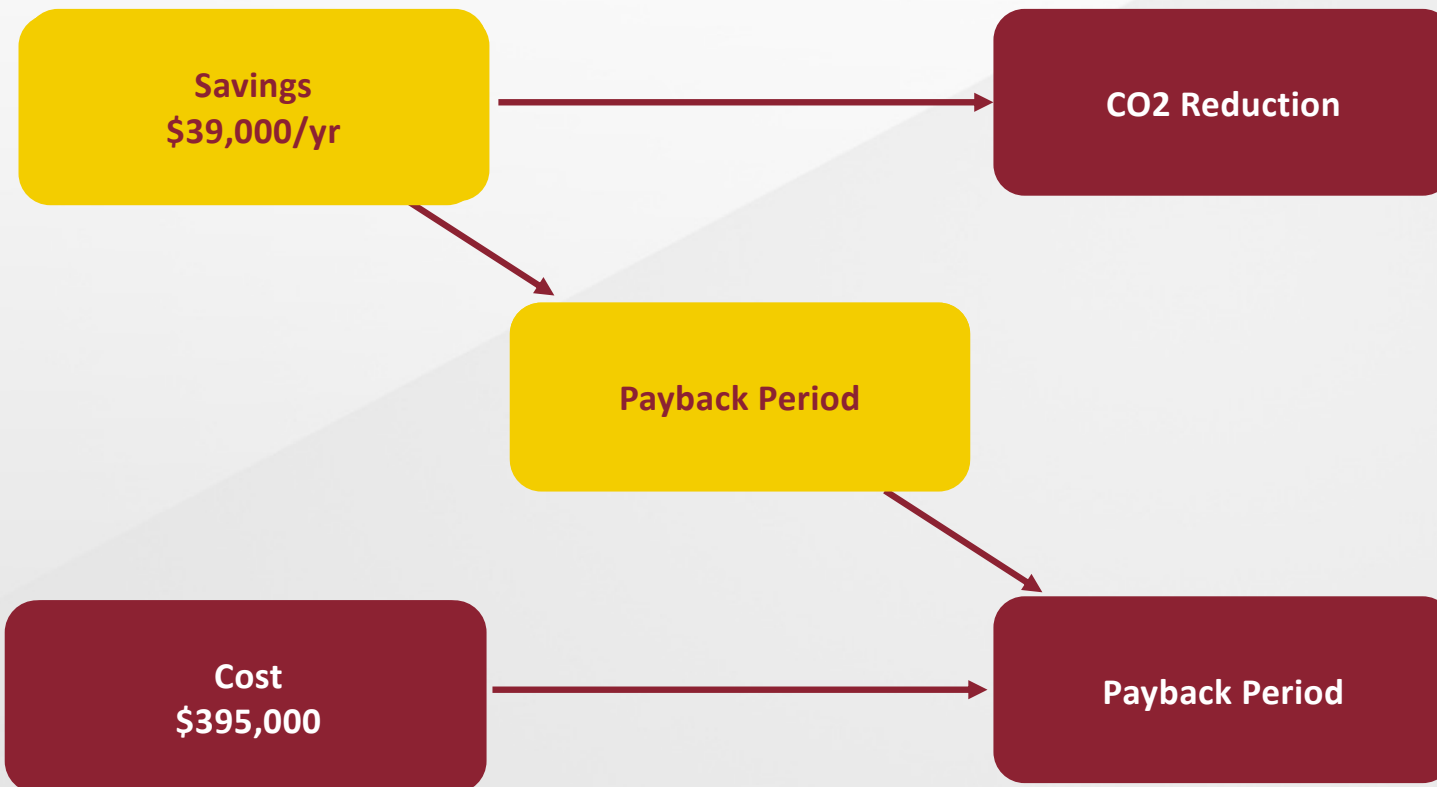
Costs – Venema Aquatic Center

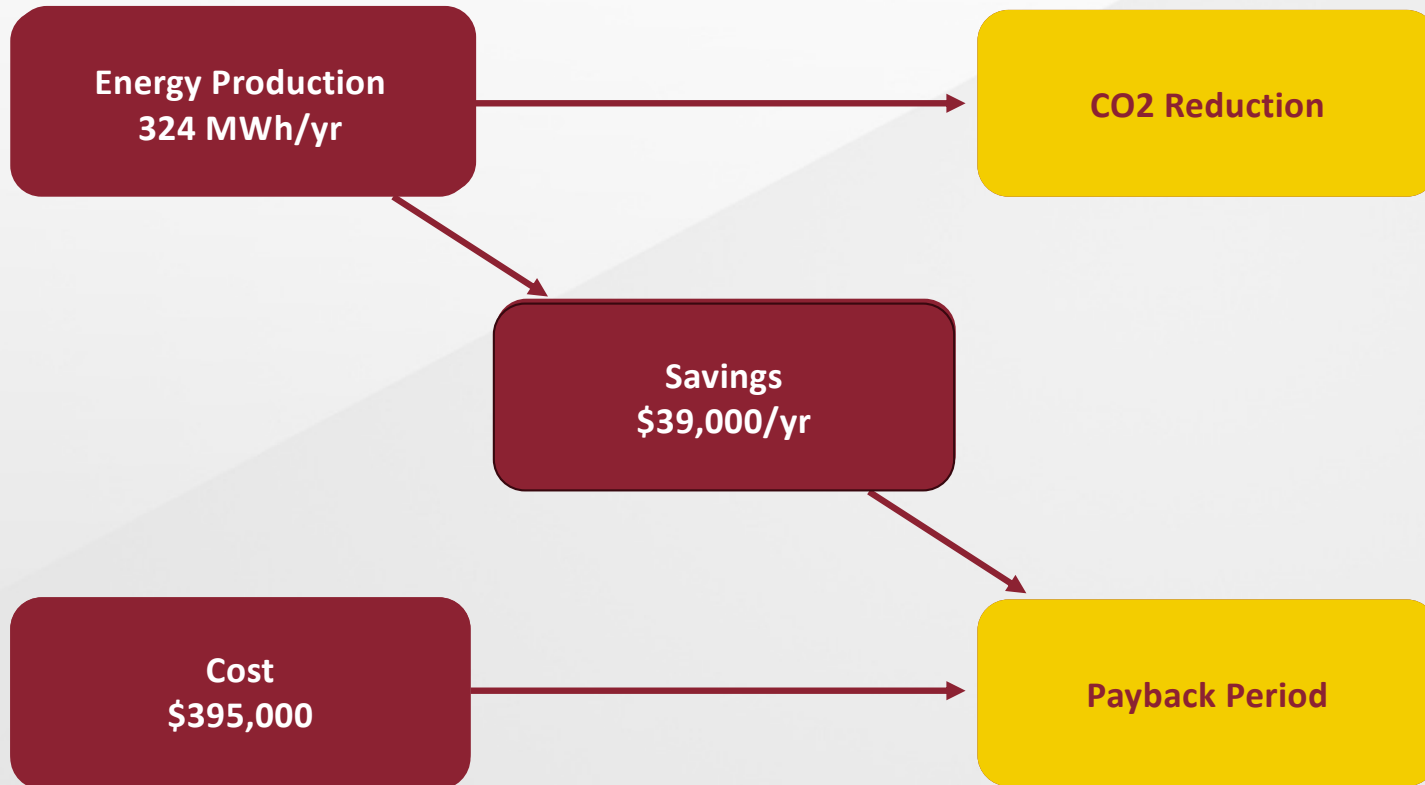
- **Total Energy Production**
 - 324 MWh / yr
- **Total Savings**
 - \$39,000 / yr





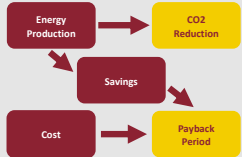






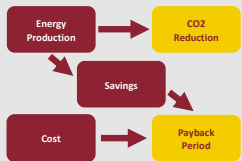
CO2 Reduction – Venema Aquatic Center

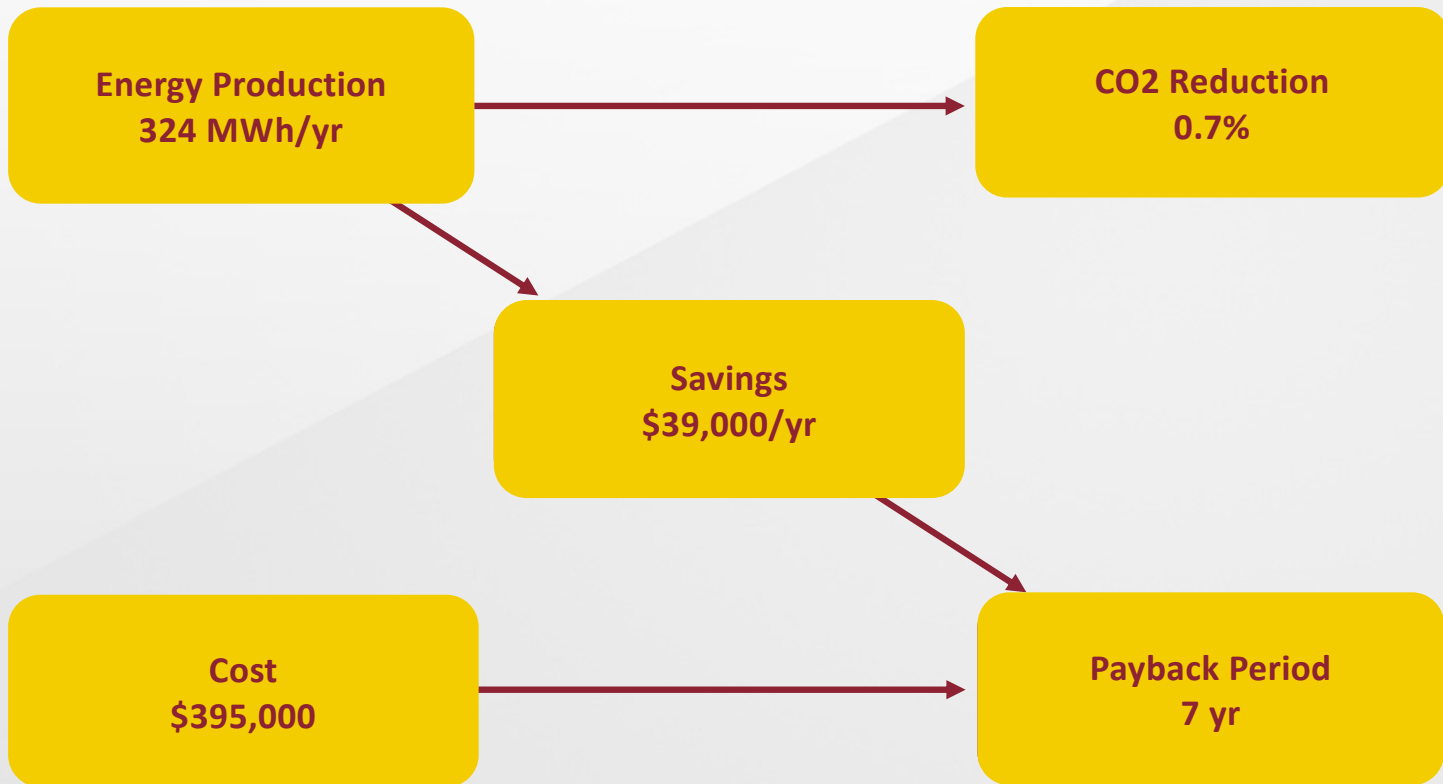
$$\frac{\text{CO2 Offset per Year}}{\text{Total CO2 Produced in 2024}} \cdot 100\% = \mathbf{0.7\%}$$



Payback Period – Venema Aquatic Center

$$\frac{\text{Total Initial Investment – Incentives}}{\text{Net Savings per Year}} \approx 7 \text{ years}$$





Venema Aquatic Center - Summary

CO2 Reduction:

0.7%

Total Initial Investment:

\$395,000

Savings:

\$39,000/yr

Payback:

7 years



Possible Locations



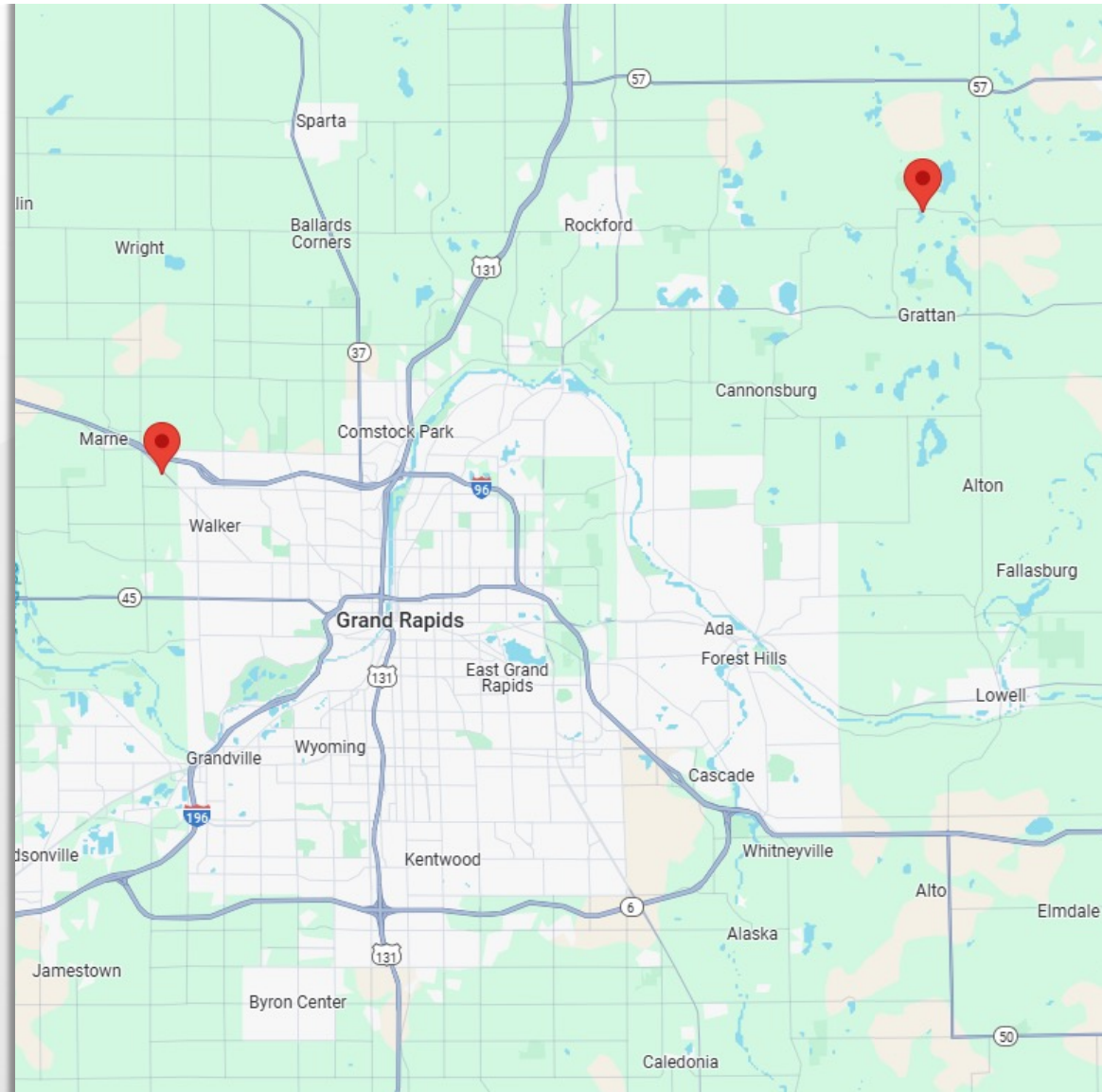
All Locations

- Roof Tops
- Parking Lots
- Open Land
- Off-Campus



All Locations

- Roof Tops
- Parking Lots
- Open Land
- Off-Campus



Best Locations

Prince Conference Center



Best Locations

Prince Conference Center
Devos Communication Center



Best Locations

Prince Conference Center

Devos Communication Center

Hekman Library and Hiemenga Hall



Best Locations

Prince Conference Center

Devos Communication Center

Hekman Library and Hiemenga Hall

Lake Drive Entrance



Best Locations

Prince Conference Center

Devos Communication Center

Hekman Library and Hiemenga Hall

Lake Drive Entrance

Seminary Field



Best Locations

Prince Conference Center

Devos Communication Center

Hekman Library and Hiemenga Hall

Lake Drive Entrance

Seminary Field

Venema Aquatic Center



Best Locations

Prince Conference Center

Devos Communication Center

Hekman Library and Hiemenga Hall

Lake Drive Entrance

Seminary Field

Venema Aquatic Center

Van Noord Arena



Prince Conference Center

CO2 Reduction:

0.5%

Payback:

7 years

Total Initial Investment:

\$304,000

Savings:

\$29,000/yr



Devos Communication Center

CO2 Reduction:

1.1%

Payback:

8 years

Total Initial Investment:

\$722,000

Savings:

\$61,000/yr



Hekman Library and Hiemenga Hall

CO2 Reduction:

2.3%

Payback:

9 years

Total Initial Investment:

\$1,804,000

Savings:

\$125,000/yr



Lake Drive Entrance

CO2 Reduction:

3.4%

Payback:

11 years

Total Initial Investment:

\$2,139,000

Savings:

\$141,000/yr



Seminary Field

CO2 Reduction:

4.2%

Payback:

12 years

Total Initial Investment:

\$2,689,000

Savings:

\$159,000/yr



Venema Aquatic Center

CO2 Reduction:

4.9%

Payback:

12 years

Total Initial Investment:

\$3,083,000

Savings:

\$181,000/yr



Van Noord Arena

CO2 Reduction:

5.8%

Payback:

12 years

Total Initial Investment:

\$3,572,000

Savings:

\$209,000/yr



Final Proposal

CO2 Reduction:

5.8%

Payback:

12 years

Total Initial Investment:

\$3,572,000

Savings:

\$209,000/yr



Final Proposal

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							✓



Final Proposal

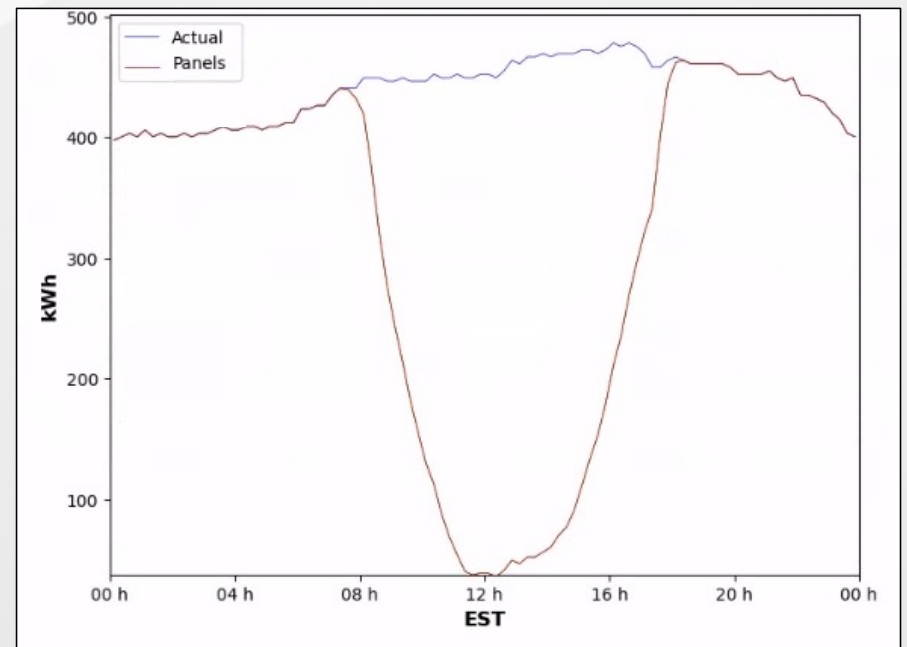
```
mytilt = 30. # Make your choice here for rooftop tilts
Panels.Tilt_deg[1] = mytilt
Panels.Tilt_deg[2] = mytilt
Panels.Tilt_deg[3] = mytilt
Panels.Tilt_deg[4] = mytilt

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
```



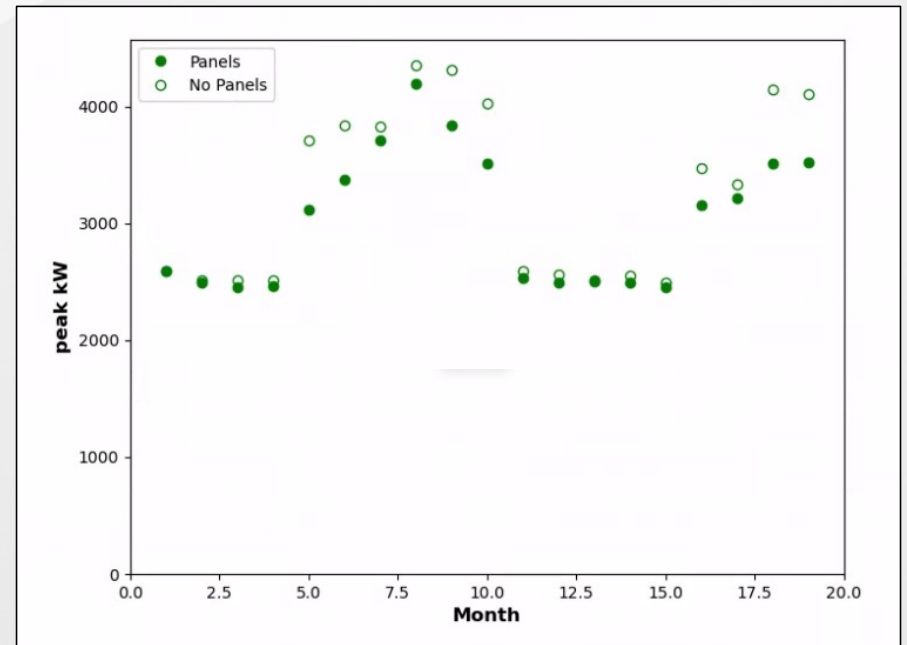
Final Proposal Results

- Daily electricity from grid



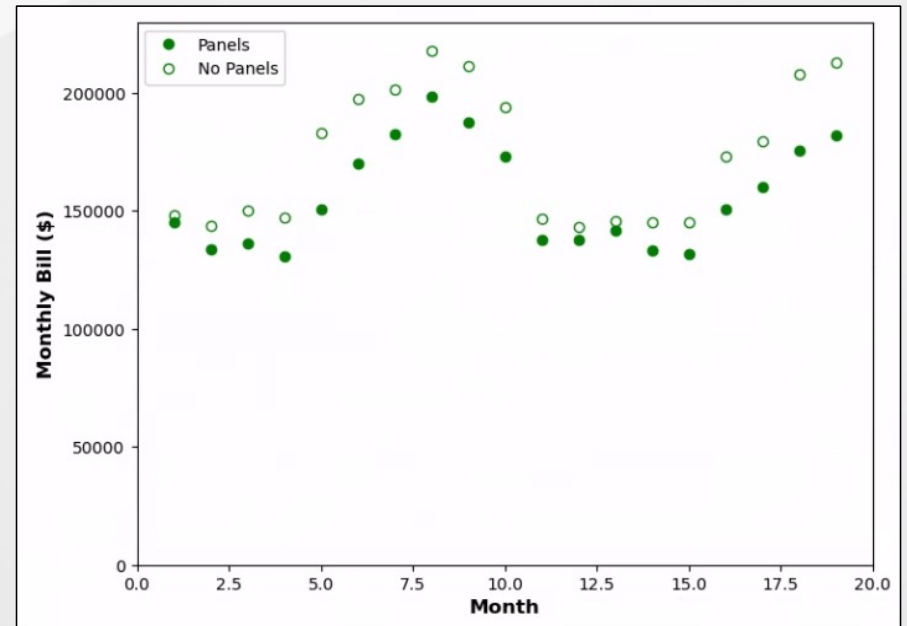
Final Proposal Results

- Daily electricity from grid
- **Peak kW Purchased**



Final Proposal Results

- Daily electricity from grid
- Peak kW Purchased
- **Monthly Bill**



Final Proposal Results

- Daily electricity from grid
- Peak kW Purchased
- Monthly Bill
- **Final Deliverables**

Summary Table				
Case	Power	Saving	Saving	Loss
	kW	M\$	GWh	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



Physics 131

Type	Name	Azimuth (deg)	Tilt (deg)	1	2	3	4	5	6	7	8
Rooftop	Aquatic Center	178	14.03	✓	✓	✓	✓	✓	✓	✓	✓
Rooftop	Van Noor Arena	164	10.3	✓	✓	✓	✓	✓	✓	✓	✓
Parking Lot	Lot 6	180	7	✓	✓	✓	✓	✓	✓	✓	✓
On-Campus Ground	Phi Chi Field Hill	adjustable	adjustable	✓	✓	✓	✓	✓	✓	✓	✓
Rooftop	Prince Conf.	180	adjustable	✓	✓	✓	✓	✓	✓	✓	✓
Rooftop	Devos Comm.	160	adjustable	✓	✓	✓	✓	✓	✓	✓	✓
Rooftop	Hekman Library	178	adjustable	✓	✓	✓	✓	✓	✓	✓	✓
Rooftop	Heimenga Hall	178	adjustable	✓	✓	✓	✓	✓	✓	✓	✓
Parking Lot	Lot 1	270	7	✓	✓	✓	✓	✓	✓	✓	✓
Parking Lot	Lot 2	270	7	✓	✓	✓	✓	✓	✓	✓	✓
Parking Lot	Lot 3	270	7	✓	✓	✓	✓	✓	✓	✓	✓
Parking Lot	Lot 4	270	7	✓	✓	✓	✓	✓	✓	✓	✓
Parking Lot	Lot 5	270	7	✓	✓	✓	✓	✓	✓	✓	✓
Parking Lot	Lot 17	250	7	✓	✓	✓	✓	✓	✓	✓	✓
Parking Lot	Lot 16	250	7	✓	✓	✓	✓	✓	✓	✓	✓
Parking Lot	Lot 15	270	7	✓	✓	✓	✓	✓	✓	✓	✓
Parking Lot	Lot 14	250	7	✓	✓	✓	✓	✓	✓	✓	✓
On-Campus Ground	Devos Field	adjustable	adjustable	✓	✓	✓	✓	✓	✓	✓	✓
On-Campus Ground	Phi Chi Field	adjustable	adjustable	✓	✓	✓	✓	✓	✓	✓	✓
On-Campus Ground	Lake Dr. Entrance	adjustable	adjustable	✓	✓	✓	✓	✓	✓	✓	✓
Parking Lot	Lot 8	200	7	✓	✓	✓	✓	✓	✓	✓	✓
Parking Lot	Lot 13	270	7	✓	✓	✓	✓	✓	✓	✓	✓
Parking Lot	Lot 11	180	7	✓	✓	✓	✓	✓	✓	✓	✓

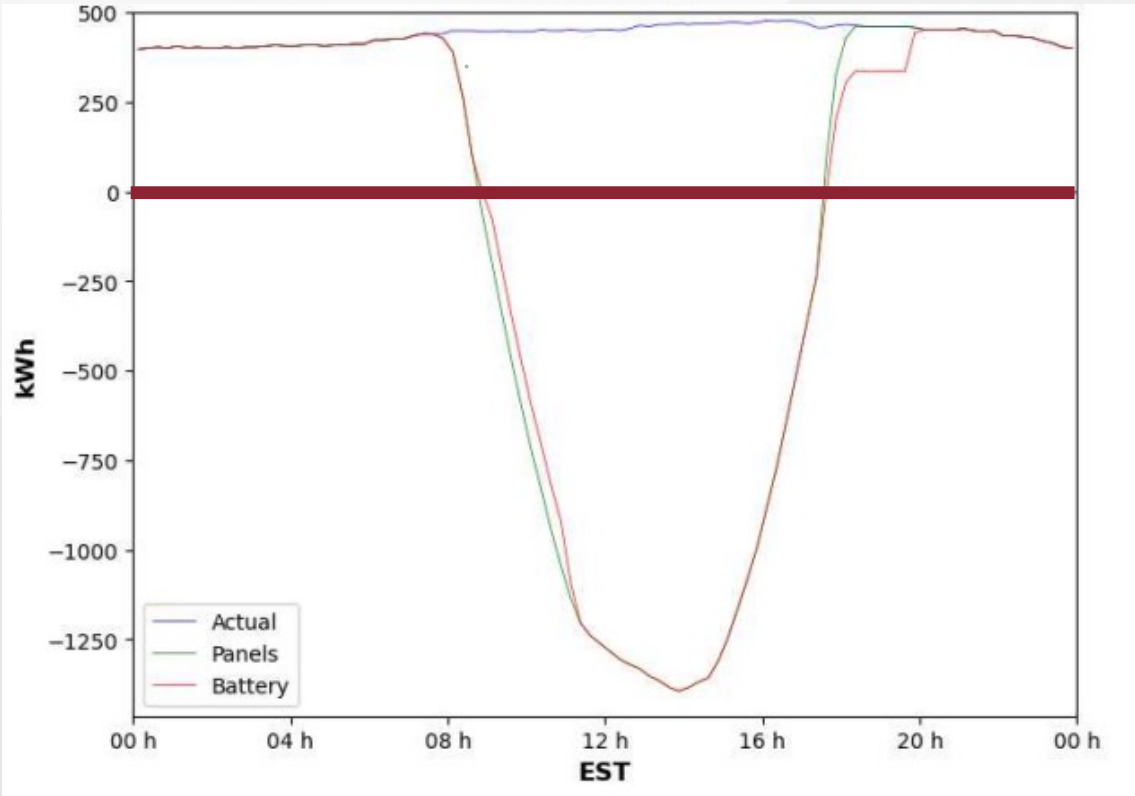


Summary Table

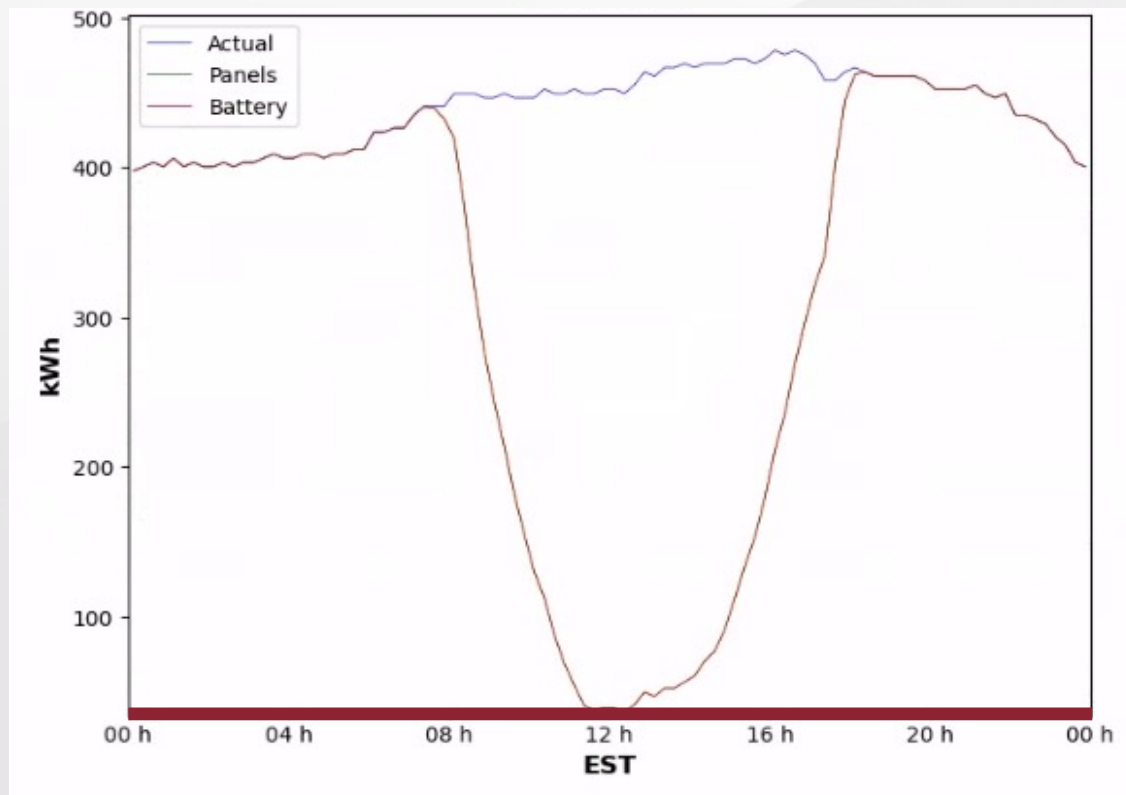
Case	Power kW	Saving M\$	Saving GWh	Loss GWh
1	1219	0.127	1.350	0.000
2	2715	0.242	3.076	0.014
3	3423	0.288	3.820	0.096
4	5020	0.361	4.935	0.591
5	7811	0.445	6.080	2.498
6	9491	0.480	6.499	3.894
7	10223	0.492	6.640	4.491
8	10453	0.496	6.685	4.694



All Projects



Final Proposal



Recommendation

Total Initial Investment:

\$3,572,000

CO2 Reduction:

5.8%

Savings:

\$209,000/yr

Payback:

12 years



The Next Steps



Next Steps for Calvin

- Carbon Neutrality by 2057
- Solar does not solve our problem

- **Possible next steps:**
 - Become more efficient
 - Track electricity consumption
 - HVAC system improvements
 - Building Envelopes
 - Geothermal Systems

Calvin commits to carbon neutrality by 2057

Rae Gemant, Head Copy Editor | December 8, 2017



Le Roy signing the Second Nature Climate Commitment. Photo by Hannah Butler.



Next Steps - Lot 11

CO2 Reduction:

6.2%

Total Initial Investment:

\$3,883,000

Savings:

\$220,000/yr

Payback:

12 years



Next Steps - Lot 19

CO2 Reduction:

6.6%

Total Initial Investment:

\$4,147,000

Savings:

\$231,000/yr

Payback:

13 years



Next Steps - Lot 8

Panels:

2,465

Inverters:

20

System Power:

1,500 kW

Total Initial Investment Alone:

\$2,506,000



Next Steps - Lot 11 + 19

Summary Table				
Case	Power	Saving	Saving	Loss
	kW	M\$	GWh	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
8	2423	0.220	2.750	0.005
9	2580	0.231	2.923	0.009



Thank you very much!



Acknowledgements

- **Dirk Pruis:** CFO of Calvin University
- **Dr. Matthew Heun:** Professor of Thermal Systems Design
- **Dr. Larry Molnar:** Professor of Physics/Observatory Director
- **Dr. Leonard De Rooy:** Professor of Civil Engineering
- **Greg Oliver:** Agathon Solar
- **Brett Hoogewind:** Associate Director of Facilities
- **Chuck Holwerda:** Electronics Shop Supervisor
- **Matthew Kucinski:** Senior Writer & Communications Strategist
- **Greg Elzinga:** President of Calvin University
- **ENGR 333:** Thermo Team
- **Physics 131:** Physics Team
- **ENGR 327:** Civil Team
- **Jennifer Ambrose:** Director of Facilities
- **Joe Russell:** Campus Electrician
- **Church of the Servant**
- **Adam Hollemans:** Church of the Servant Informant
- **Brian Hiemstra:** Arborist Representative
- **Yoly Young:** SunforSon
- **Jamie Skillen:** Professor of Geo.
- **Mark Luehmann:** Consumers Energy
- **Nicholas Tenney:** Consumers Energy
- **Dave Warners:** Professor of Biology



Acknowledgements

Professor Matthew Heun, for his unending wisdom, patience, and guidance throughout this project.

Thank you,
ENGR 333



Questions?



Appendix

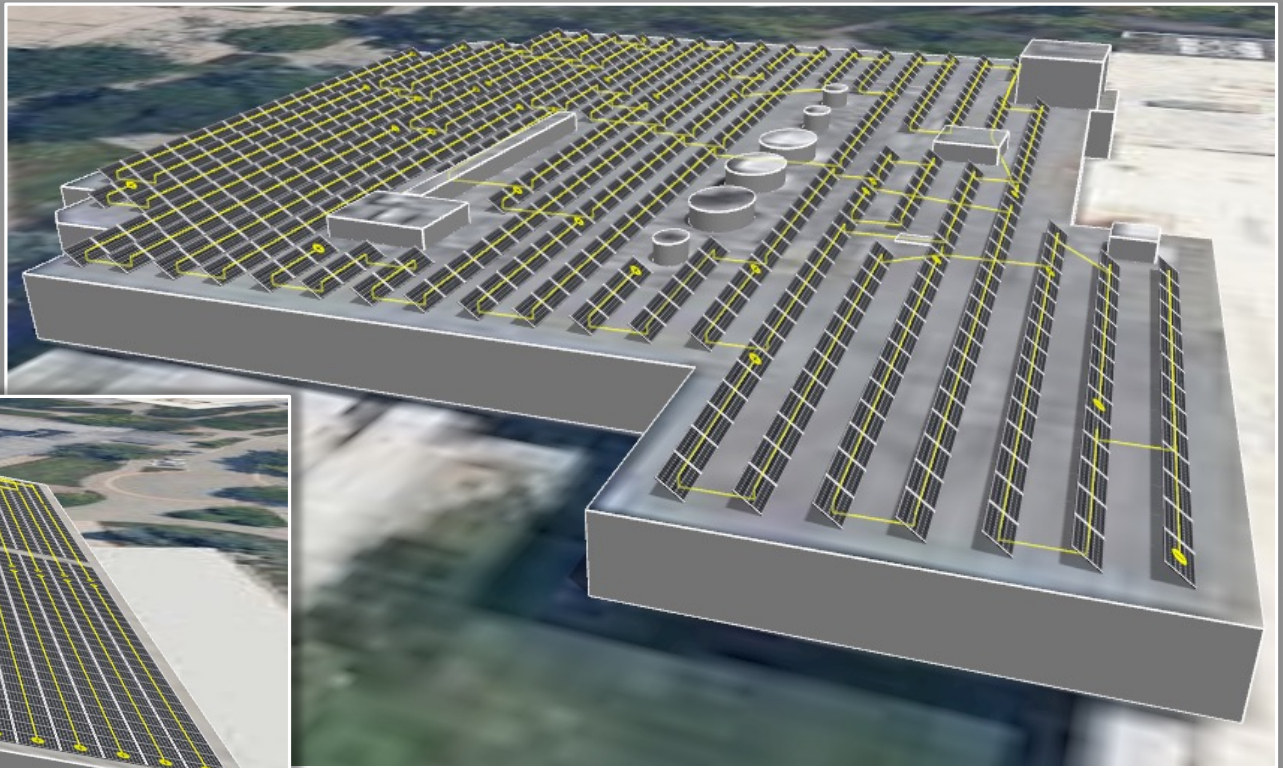


Civil Team

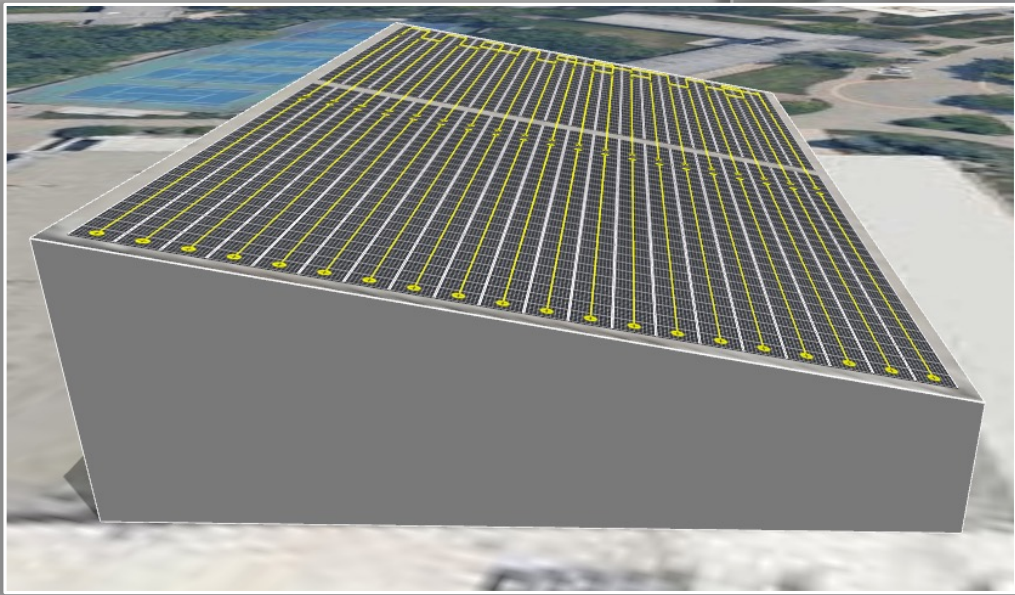
- Structural Capacity
 - Estimated 7 lb/ft²
 - Snow Drift



PHYS 131 - Tilt



Hekman Library



Van Noord



Combining Projects

- The 3P framework
 - Projects -> Packages -> Progressions

"Project"
Venema Aquatic Center Roof

"Package"
Venema Aquatic Center Roof
Parking Lot #8
Prince Conference Center Roof

"Progression"		
TRUE	TRUE	TRUE
FALSE	TRUE	TRUE
FALSE	FALSE	TRUE

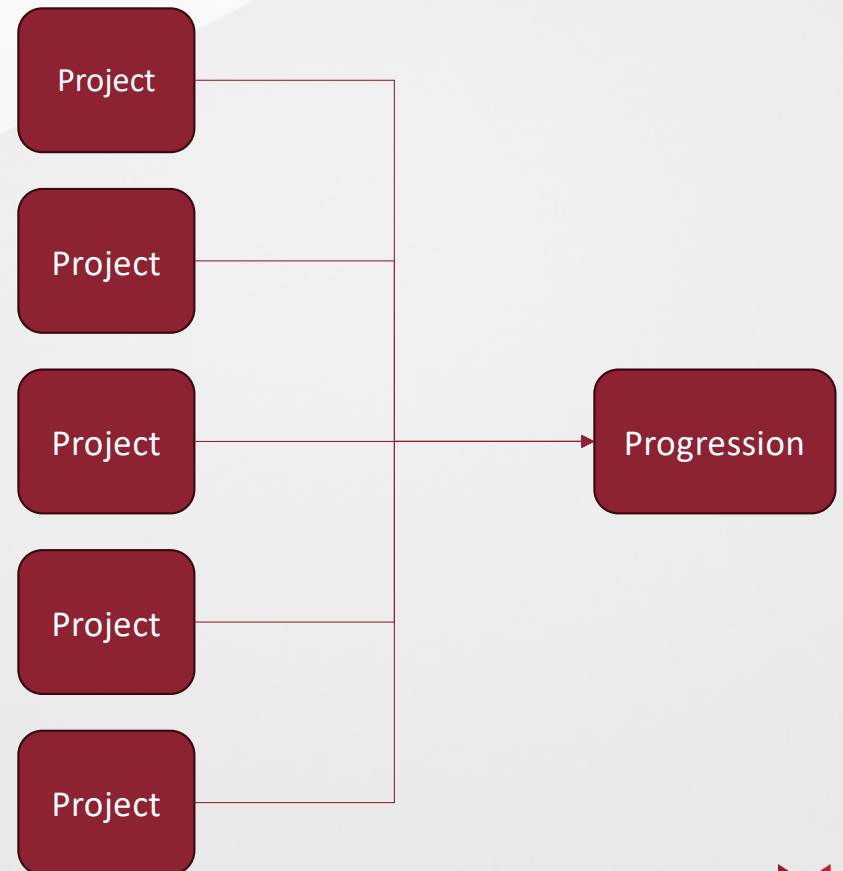


Irradiance Month	Irradiance [kWh/m ² -day]
Jan	1.49
Feb	2.29
Mar	4
Apr	4.89
May	6.05
Jun	6.6
Jul	6.52
Aug	5.57
Sep	4.47
Oct	2.83
Nov	1.69
Dec	1.06



Combining Projects

- The 3P framework
 - Projects -> Packages -> Progressions
- CO₂ Emission Reduction
- Cost
- Energy Production?
- Financial Savings?



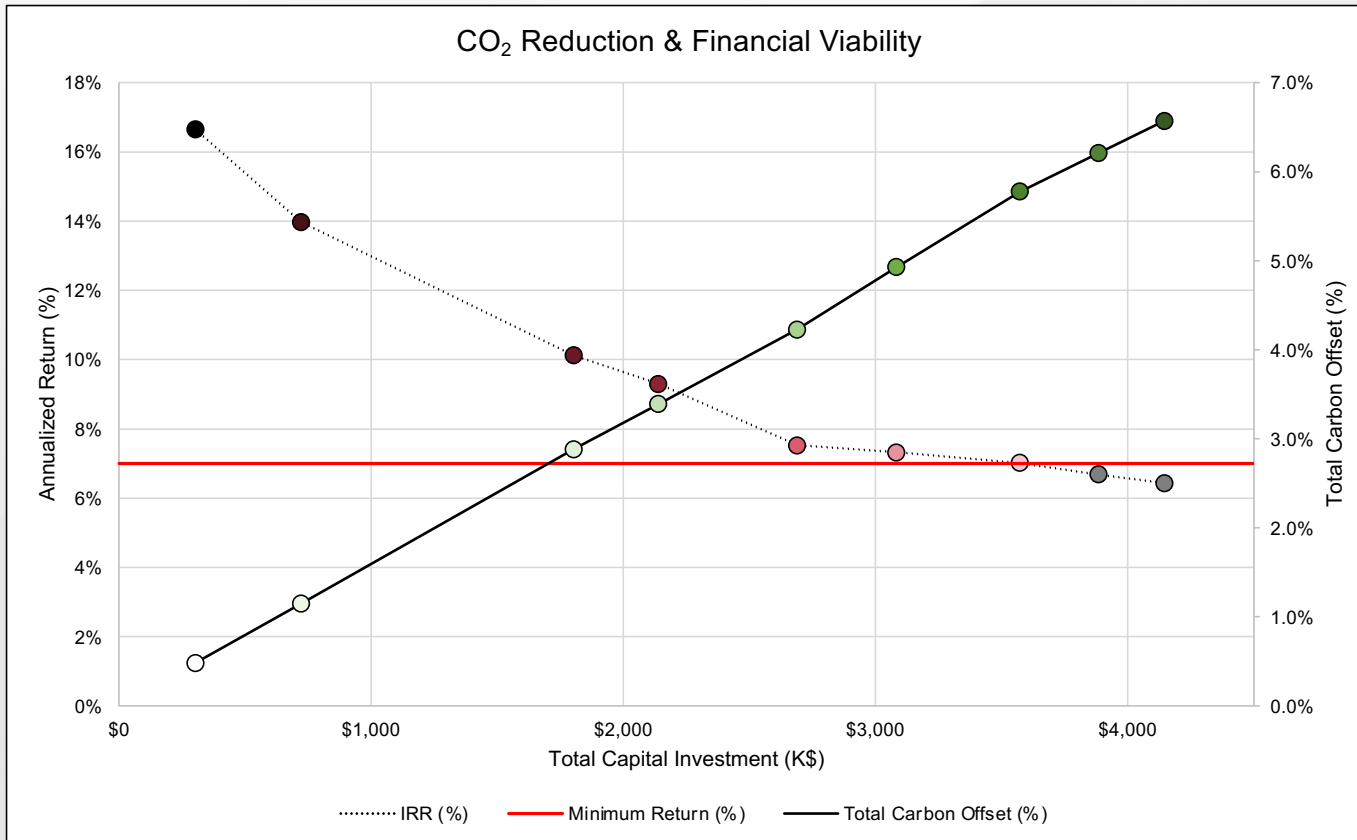
Case Study

Mounting Type	Solar Panel [\$/W]	Installation [\$/W]	Racking [\$/W]	Grid Installation [\$/W]	Total [\$/W]
Slanted Rooftop	0.39	0.5	0.26	0.15	1.3
Flat Rooftop	0.39	0.5	0.43	0.15	1.47
Parking Lot	0.25	0.5	0.57	0.3	1.62
Ground	0.41	0.5	0.5	0.3	1.71

Panel Name	Peak Power [W]	Efficiency [%]	Area [m ²]
TOPBiHiKu7	720	24.30%	3.106
TigerNeo	605	23.42%	2.583
Silfab 430QD	430	22.10%	1.95



Progression Results



Financial Considerations

- **MARR:** 7%
- **Lifespan of System:** 20 years
- **Inflation Rate:** 3.68%
- **Inflation Adjusted Energy Rate:** 0.241%
- **Incentives:** 30%



PROJECT	Carbon Neutrality of Electricity [%]	PROJECT	30-Year Internal Rate of Return [%]	PROJECT	First Year Energy/Initial Investment [kWh/\$]	PROJECT	Total Initial Investment
Flat Iron Lake Prairie	17.0%	Roof - Aquatic Center	14.0%	Roof - Aquatic Center	0.92	Parking Lot 5	\$ (209,896)
Eco Preserve Prairie	9.2%	Roof - Van Noord Arena	13.6%	Roof - Van Noord Arena	0.90	Parking Lot 19	\$ (263,801)
Parking Lot 8	3.5%	Roof - HH + Hekman Lib	12.7%	Roof - HH + Hekman Lib	0.83	Roof - Prince Conf Center	\$ (303,853)
Phi Chi Field	2.9%	Roof - North Hall	12.7%	Roof - North Hall	0.83	Parking Lot 4	\$ (307,906)
Devos Field	2.8%	Roof - Devos Comm	12.6%	Roof - Devos Comm	0.83	Parking Lot 11	\$ (310,846)
Flat Iron Lake Near House	2.0%	Roof - Prince Conf Center	12.5%	Roof - Prince Conf Center	0.83	Lake Drive Lawn	\$ (334,975)
Cross-Country Track Forest	1.8%	Phi Chi Field Hill	12.4%	Phi Chi Field Hill	0.79	Roof - North Hall	\$ (360,160)
Roof - HH + Hekman Lib	1.7%	Seminary Field	12.3%	Seminary Field	0.79	Parking Lot 14	\$ (381,000)
Parking Lot 13	1.6%	Flat Iron Lake Near House	12.3%	Flat Iron Lake Near House	0.79	Roof - Aquatic Center	\$ (393,974)
Parking Lot 1	1.5%	Phi Chi Field	12.3%	Phi Chi Field	0.79	Roof - Devos Comm	\$ (417,791)
Joose House Property	1.3%	Eco Preserve Prairie	12.3%	Eco Preserve Prairie	0.79	Phi Chi Field Hill	\$ (435,987)
Parking Lot 16	1.3%	Flat Iron Lake Prairie	12.3%	Flat Iron Lake Prairie	0.79	Parking Lot 3	\$ (473,697)
Roof - Van Noord Arena	0.8%	Devos Field	12.3%	Devos Field	0.79	Roof - Van Noord Arena	\$ (489,110)
Seminary Field	0.8%	Cross-Country Track Forest	12.3%	Cross-Country Track Forest	0.79	Parking Lot 2	\$ (517,802)
Parking Lot 17	0.8%	Joose House Property	12.2%	Joose House Property	0.79	Parking Lot 15	\$ (547,205)
Parking Lot 6	0.8%	Lake Drive Lawn	12.1%	Lake Drive Lawn	0.78	Seminary Field	\$ (550,109)
Parking Lot 15	0.7%	Parking Lot 11	10.8%	Parking Lot 11	0.72	Parking Lot 6	\$ (561,906)
Roof - Aquatic Center	0.7%	Parking Lot 6	10.8%	Parking Lot 6	0.72	Parking Lot 17	\$ (590,896)
Parking Lot 2	0.7%	Parking Lot 19	10.7%	Parking Lot 19	0.72	Flat Iron Lake Near House	\$ (816,540)
Roof - Devos Comm	0.7%	Parking Lot 8	10.7%	Parking Lot 8	0.72	Joose House Property	\$ (872,766)
Phi Chi Field Hill	0.7%	Parking Lot 14	10.1%	Parking Lot 14	0.69	Parking Lot 16	\$ (966,996)
Parking Lot 3	0.6%	Parking Lot 16	10.1%	Parking Lot 16	0.69	Roof - HH + Hekman Lib	\$ (1,082,378)
Roof - North Hall	0.6%	Parking Lot 17	10.1%	Parking Lot 17	0.69	Cross-Country Track Forest	\$ (1,158,907)
Parking Lot 14	0.5%	Parking Lot 4	10.0%	Parking Lot 4	0.68	Parking Lot 1	\$ (1,172,404)
Lake Drive Lawn	0.5%	Parking Lot 15	9.9%	Parking Lot 15	0.68	Parking Lot 13	\$ (1,230,797)
Roof - Prince Conf Center	0.5%	Parking Lot 1	9.9%	Parking Lot 1	0.68	Devos Field	\$ (1,819,442)
Parking Lot 11	0.4%	Parking Lot 2	9.9%	Parking Lot 2	0.68	Phi Chi Field	\$ (1,884,730)
Parking Lot 4	0.4%	Parking Lot 13	9.8%	Parking Lot 13	0.67	Parking Lot 8	\$ (2,505,699)
Parking Lot 19	0.4%	Parking Lot 3	9.8%	Parking Lot 3	0.67	Eco Preserve Prairie	\$ (6,035,976)
Parking Lot 5	0.3%	Parking Lot 5	9.7%	Parking Lot 5	0.67	Flat Iron Lake Prairie	\$ (9,132,143)

Top 10 Locations

PROJECT	Carbon Neutrality of Electricity [%]	PROJECT	30-Year Internal Rate of Return [%]	PROJECT	First Year Energy/Initial Investment [kWh/\$]	PROJECT	Total Initial Investment
Flat Iron Lake Prairie	17.0%	Roof - Aquatic Center	14.0%	Roof - Aquatic Center	0.92	Parking Lot 5	\$ (209,896)
Eco Preserve Prairie	9.2%	Roof - Van Noord Arena	13.6%	Roof - Van Noord Arena	0.90	Parking Lot 19	\$ (263,801)
Parking Lot 8	3.5%	Roof - HH + Hekman Lib	12.7%	Roof - HH + Hekman Lib	0.83	Roof - Prince Conf Center	\$ (303,853)
Phi Chi Field	2.9%	Roof - North Hall	12.7%	Roof - North Hall	0.83	Parking Lot 4	\$ (307,906)
Devos Field	2.8%	Roof - Devos Comm	12.6%	Roof - Devos Comm	0.83	Parking Lot 11	\$ (310,846)
Flat Iron Lake Near House	2.0%	Roof - Prince Conf Center	12.5%	Roof - Prince Conf Center	0.83	Lake Drive Lawn	\$ (334,975)
Cross-Country Track Forest	1.8%	Phi Chi Field Hill	12.4%	Phi Chi Field Hill	0.79	Roof - North Hall	\$ (360,160)
Roof - HH + Hekman Lib	1.7%	Seminary Field	12.3%	Seminary Field	0.79	Parking Lot 14	\$ (381,000)
Parking Lot 13	1.6%	Flat Iron Lake Near House	12.3%	Flat Iron Lake Near House	0.79	Roof - Aquatic Center	\$ (393,974)
Parking Lot 1	1.5%	Phi Chi Field	12.3%	Phi Chi Field	0.79	Roof - Devos Comm	\$ (417,791)



Mounting Type	Location	System Power [kW]	Inverter Amt.	Racking	Inverters	Solar Panel	Structure Installation	Grid Installation	Annual	PECTotal	Total Intial Investment
Parking Lot	Parking Lot 1	698.8	9	\$ (398,302)	\$ (40,389)	\$ (174,694)	\$ (349,388)	\$ (209,633)	\$ (13,976)	\$ (613,384)	\$ (1,172,404)
Parking Lot	Parking Lot 2	308.6	4	\$ (175,874)	\$ (17,951)	\$ (77,138)	\$ (154,275)	\$ (92,565)	\$ (6,171)	\$ (270,962)	\$ (517,802)
Parking Lot	Parking Lot 3	281.3	4	\$ (160,355)	\$ (17,951)	\$ (70,331)	\$ (140,663)	\$ (84,398)	\$ (5,627)	\$ (248,637)	\$ (473,697)
Parking Lot	Parking Lot 4	184.5	2	\$ (105,179)	\$ (8,975)	\$ (46,131)	\$ (92,263)	\$ (55,358)	\$ (3,691)	\$ (160,286)	\$ (307,906)
Parking Lot	Parking Lot 5	124.0	2	\$ (70,694)	\$ (8,975)	\$ (31,006)	\$ (62,013)	\$ (37,208)	\$ (2,481)	\$ (110,676)	\$ (209,896)
Parking Lot	Parking Lot 6	335.8	4	\$ (191,392)	\$ (17,951)	\$ (83,944)	\$ (167,888)	\$ (100,733)	\$ (6,716)	\$ (293,286)	\$ (561,906)
Parking Lot	Parking Lot 8	1491.3	20	\$ (850,055)	\$ (89,753)	\$ (372,831)	\$ (745,663)	\$ (447,398)	\$ (29,827)	\$ (1,312,639)	\$ (2,505,699)
Parking Lot	Parking Lot 11	186.3	2	\$ (106,214)	\$ (8,975)	\$ (46,585)	\$ (93,170)	\$ (55,902)	\$ (3,727)	\$ (161,774)	\$ (310,846)
Parking Lot	Parking Lot 13	732.1	10	\$ (417,269)	\$ (44,876)	\$ (183,013)	\$ (366,025)	\$ (219,615)	\$ (14,641)	\$ (645,157)	\$ (1,230,797)
Parking Lot	Parking Lot 14	226.9	3	\$ (129,319)	\$ (13,463)	\$ (56,719)	\$ (113,438)	\$ (68,063)	\$ (4,538)	\$ (199,500)	\$ (381,000)
Parking Lot	Parking Lot 15	326.7	4	\$ (186,219)	\$ (17,951)	\$ (81,675)	\$ (163,350)	\$ (98,010)	\$ (6,534)	\$ (285,845)	\$ (547,205)
Parking Lot	Parking Lot 16	574.8	8	\$ (327,608)	\$ (35,901)	\$ (143,688)	\$ (287,375)	\$ (172,425)	\$ (11,495)	\$ (507,196)	\$ (966,996)
Parking Lot	Parking Lot 17	350.9	5	\$ (200,013)	\$ (22,438)	\$ (87,725)	\$ (175,450)	\$ (105,270)	\$ (7,018)	\$ (310,176)	\$ (590,896)
Parking Lot	Parking Lot 19	157.3	2	\$ (89,661)	\$ (8,975)	\$ (39,325)	\$ (78,650)	\$ (47,190)	\$ (3,146)	\$ (137,961)	\$ (263,801)
Rooftop Slanted	Roof - Aquatic Center	289.0	4	\$ (75,130)	\$ (17,951)	\$ (113,070)	\$ (144,480)	\$ (43,344)	\$ (5,779)	\$ (206,150)	\$ (393,974)
Rooftop Flat	Roof - North Hall	235.6	3	\$ (101,325)	\$ (13,463)	\$ (92,206)	\$ (117,820)	\$ (35,346)	\$ (4,713)	\$ (206,994)	\$ (360,160)
Rooftop Flat	Roof - Devos Comm	271.8	4	\$ (116,857)	\$ (17,951)	\$ (106,340)	\$ (135,880)	\$ (40,764)	\$ (5,435)	\$ (241,147)	\$ (417,791)
Rooftop Flat	Roof - Prince Conf Center	197.4	3	\$ (84,869)	\$ (13,463)	\$ (77,231)	\$ (98,685)	\$ (29,606)	\$ (3,947)	\$ (175,563)	\$ (303,853)
Rooftop Flat	Roof - HH + Hekman Lib	708.2	9	\$ (304,530)	\$ (40,389)	\$ (277,123)	\$ (354,105)	\$ (106,232)	\$ (14,164)	\$ (622,042)	\$ (1,082,378)
Rooftop Slanted	Roof - Van Noord Arena	358.6	5	\$ (93,241)	\$ (22,438)	\$ (140,328)	\$ (179,310)	\$ (53,793)	\$ (7,172)	\$ (256,007)	\$ (489,110)
Ground	Eco Preserve Prairie	3409.9	45	\$ (1,704,960)	\$ (201,944)	\$ (1,401,136)	\$ (1,704,960)	\$ (1,022,976)	\$ (68,198)	\$ (3,308,040)	\$ (6,035,976)
Ground	Cross-Country Track Forest	653.8	9	\$ (326,880)	\$ (40,389)	\$ (268,630)	\$ (326,880)	\$ (196,128)	\$ (13,075)	\$ (635,899)	\$ (1,158,907)
Ground	Phi Chi Field	1064.9	14	\$ (532,440)	\$ (62,827)	\$ (437,559)	\$ (532,440)	\$ (319,464)	\$ (21,298)	\$ (1,032,826)	\$ (1,884,730)
Ground	Phi Chi Field Hill	247.0	3	\$ (123,480)	\$ (13,463)	\$ (101,476)	\$ (123,480)	\$ (74,088)	\$ (4,939)	\$ (238,419)	\$ (435,987)
Ground	Devos Field	1026.7	14	\$ (513,360)	\$ (62,827)	\$ (421,879)	\$ (513,360)	\$ (308,016)	\$ (20,534)	\$ (998,066)	\$ (1,819,442)
Ground	Joose House Property	491.8	7	\$ (245,880)	\$ (31,413)	\$ (202,064)	\$ (245,880)	\$ (147,528)	\$ (9,835)	\$ (479,358)	\$ (872,766)
Ground	Lake Drive Lawn	187.9	3	\$ (93,960)	\$ (13,463)	\$ (77,216)	\$ (93,960)	\$ (56,376)	\$ (3,758)	\$ (184,639)	\$ (334,975)
Ground	Seminary Field	311.0	4	\$ (155,520)	\$ (17,951)	\$ (127,806)	\$ (155,520)	\$ (93,312)	\$ (6,221)	\$ (301,277)	\$ (550,109)
Ground	Flat Iron Lake Prairie	5156.6	69	\$ (2,578,320)	\$ (309,647)	\$ (2,118,863)	\$ (2,578,320)	\$ (1,546,992)	\$ (103,133)	\$ (5,006,831)	\$ (9,132,143)
Ground	Flat Iron Lake Near House	461.5	6	\$ (230,760)	\$ (26,926)	\$ (189,639)	\$ (230,760)	\$ (138,456)	\$ (9,230)	\$ (447,324)	\$ (816,540)



Power Calculation

Team 1

- Sunny Design



Team 2

- Hand Calculations

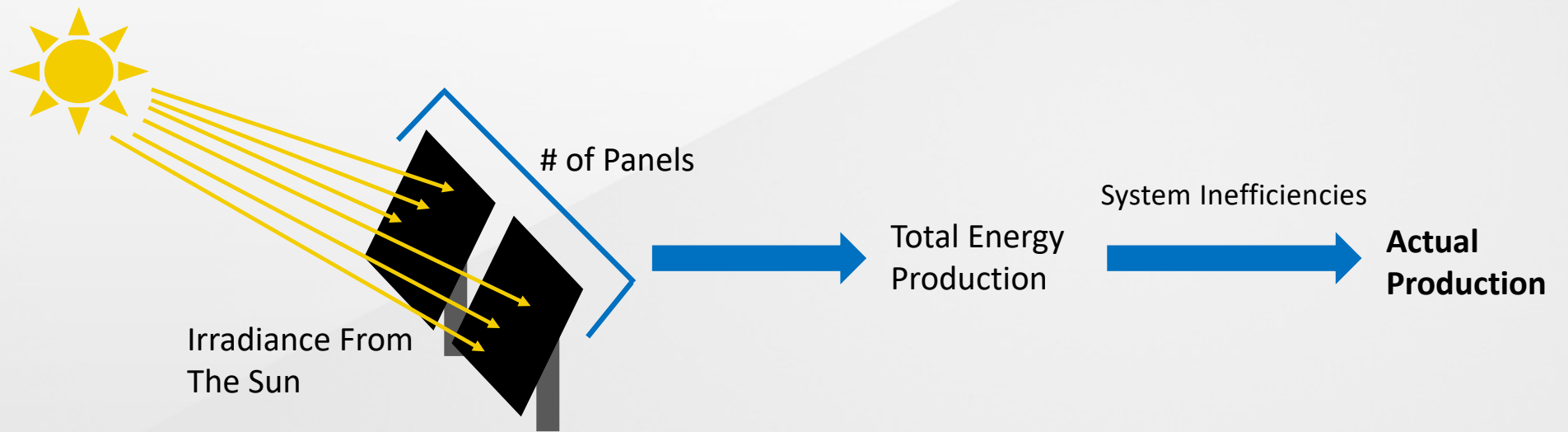
Irradiance [kWh/m ² -day]	Solar Energy on panels for each month
1.49	32273
2.29	44801
4	86639
4.89	102500
6.05	131042
6.6	138343
6.52	141222
5.57	120645
4.47	93696
2.83	61297
1.69	35424
1.06	22959

Physics Team

- Physical Model

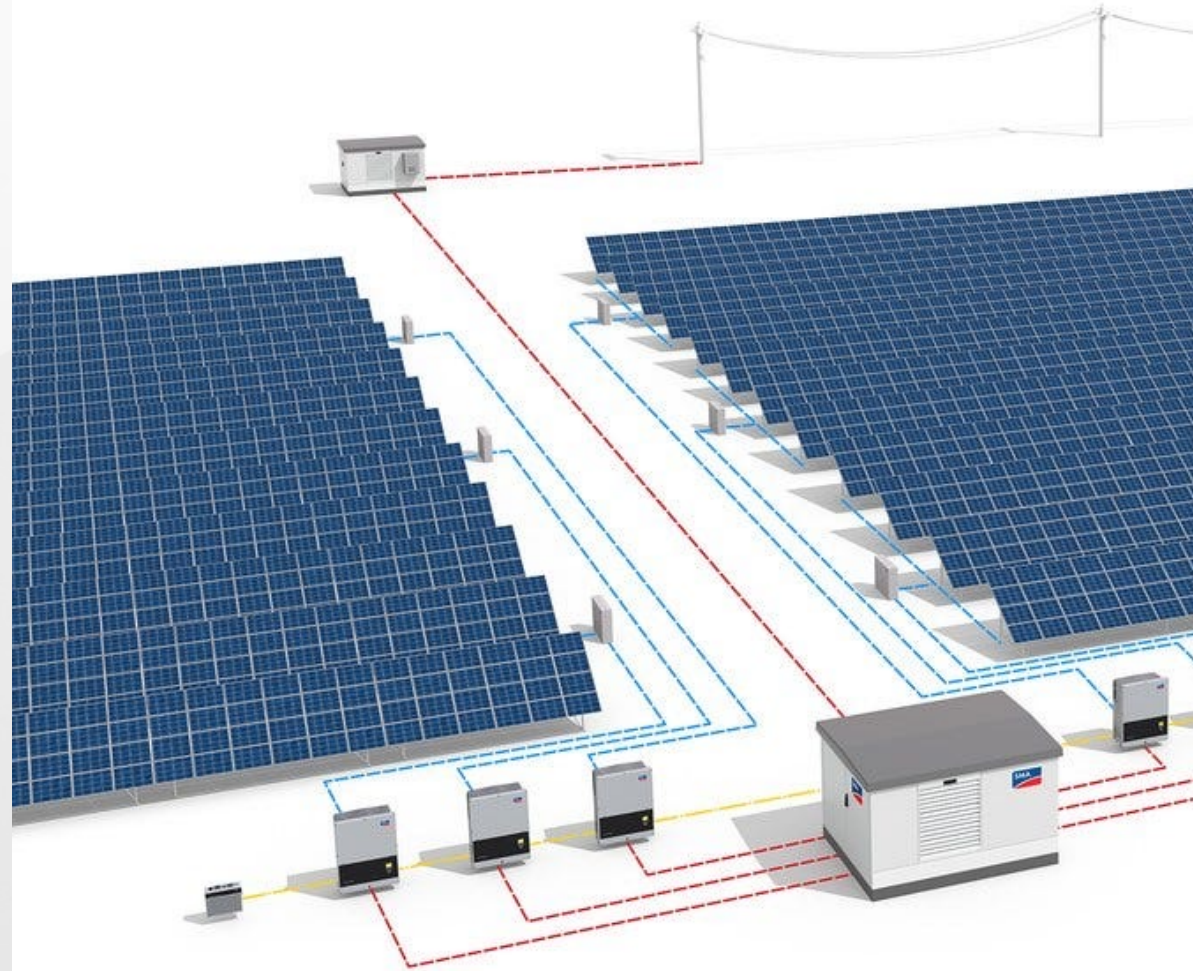


How does Solar work?



Power Losses

- Line Losses 1 - 2%
- Inverter losses 2 - 4%
- Panel Degradation
 - First Year 1 - 2%
 - Years After 0.1 - 0.5%
- Shading
- System Defects



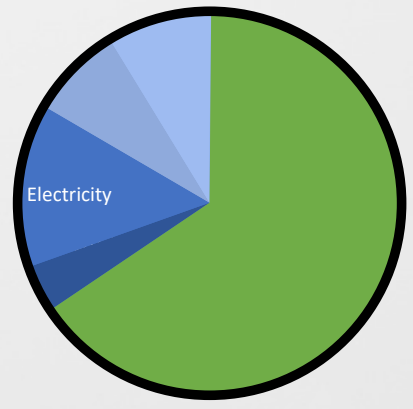
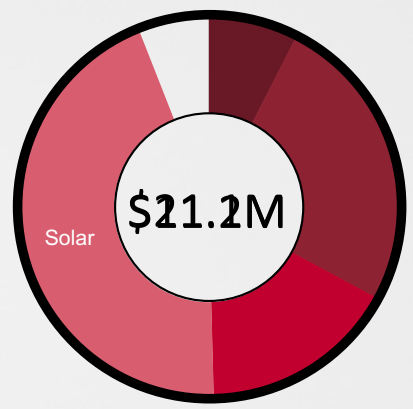


Calvin Solar Farm

\$9.9 million

38% of electricity

- Roof Top Solar
- Parking Lot 8 Solar



PHYS 131 - Obstructions



Lake Dr Entrance



Parking Lot #1

