Experimental Field Trial of Self-Cleaning Solar PV Panels

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ASEE, Salt Lake City, UT
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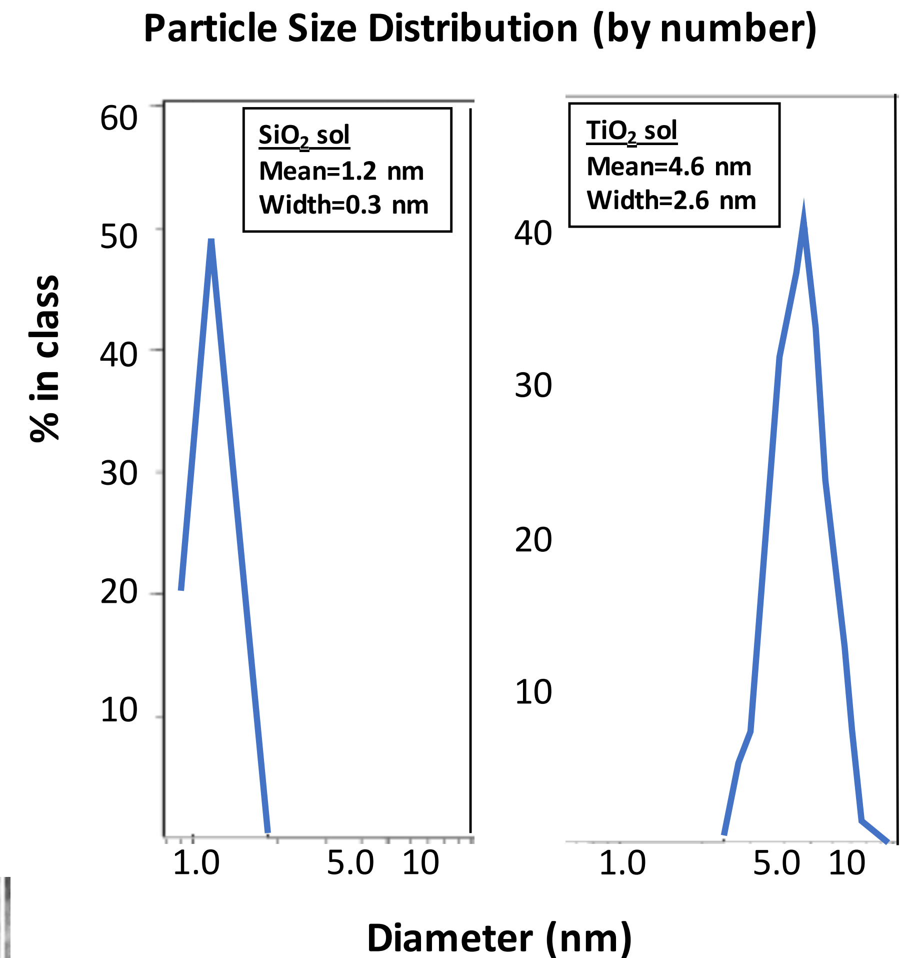
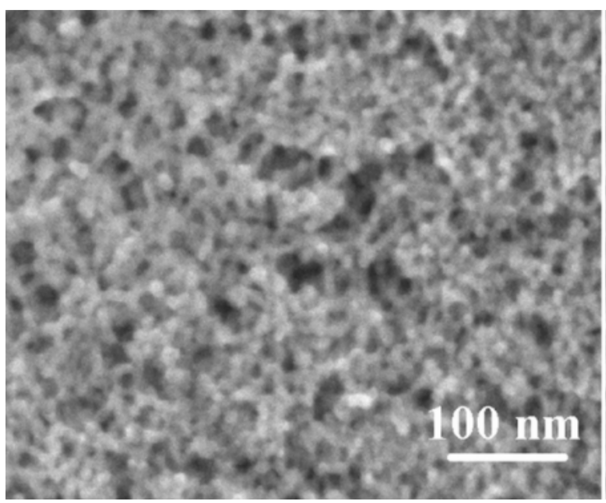
WHAT IS WRONG WITH THIS PICTURE?

Self- Cleaning Coatings for Solar Panels

SiO_2 TiO_2

Light scattering by nanoparticles





The Coatings are:

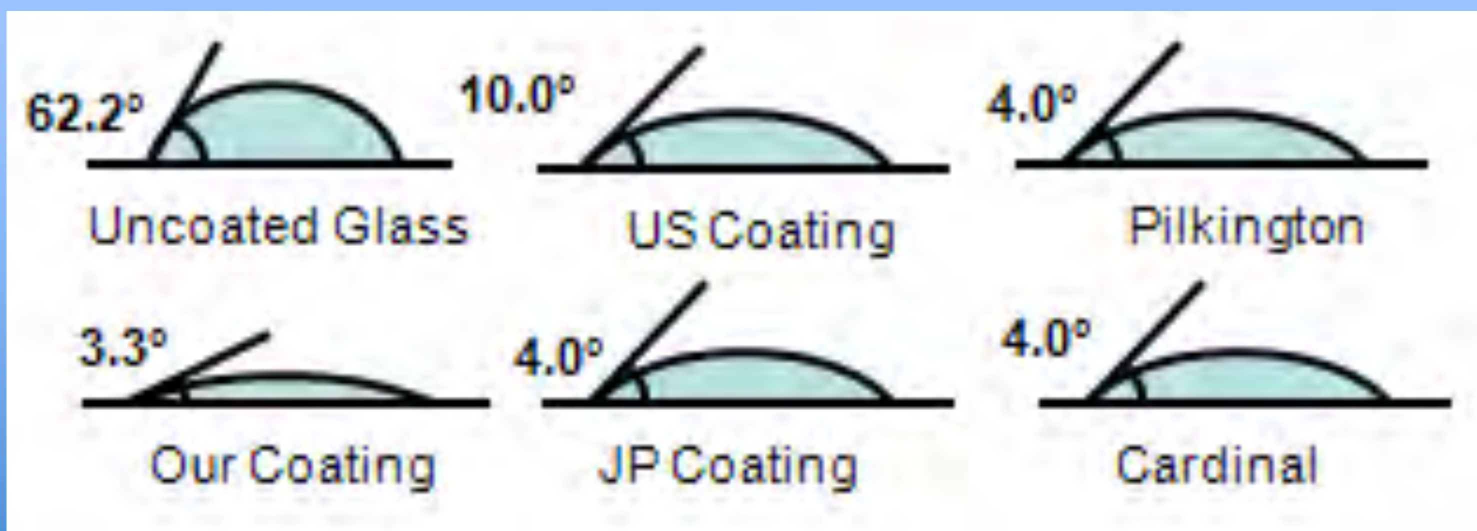
Thin (<100nm)
Nanoporous
Transparent
Durable

THE UNIVERSITY of WISCONSIN MADISON

Self- Cleaning Coatings for Solar Panels

H y d r o p h i l i c

The company's coating creates a hydrophilic surface where rain water is easily attracted. Water molecules are absorbed into the surface helping water to sheet and wash away residues.

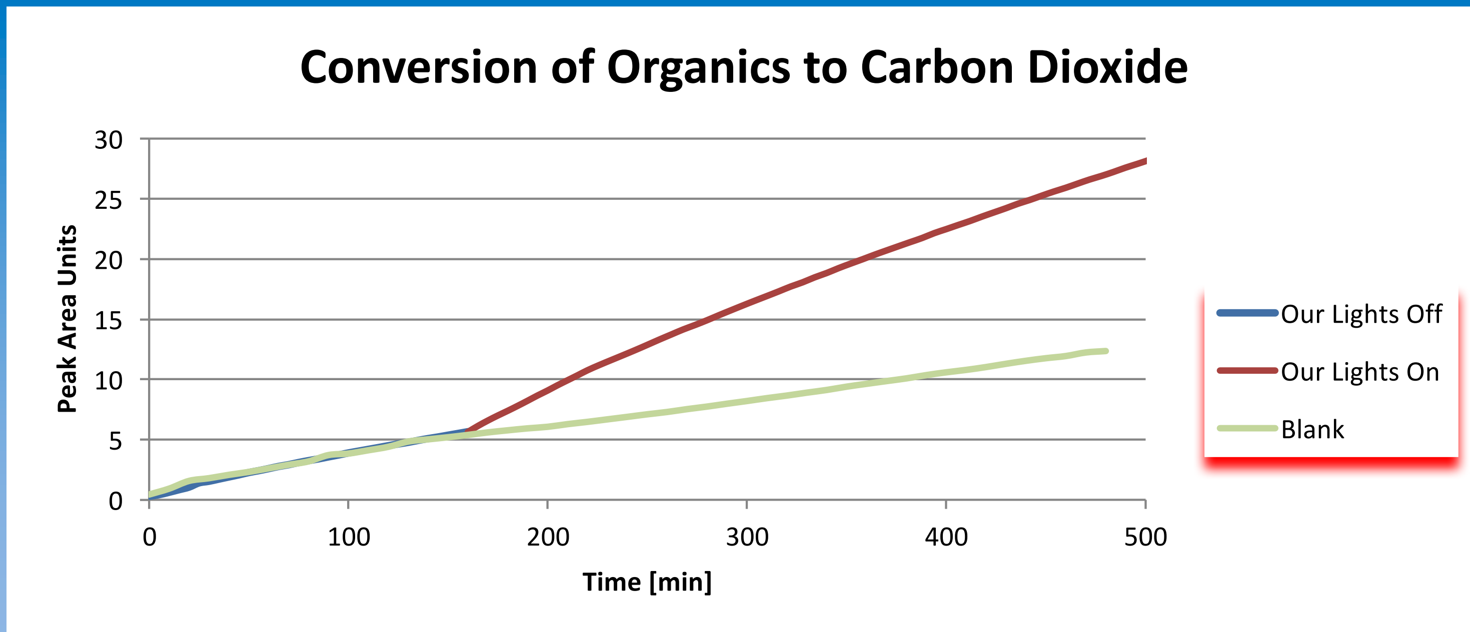


Contact Angle Test: Measurements were conducted by placing a drop of ultra pure water on the surface and measuring the angle between the substrate and a line tangent to the droplet surface.

Self- Cleaning Coatings for Solar Panels

P h o t o c a t a l y t i c

Self cleaning includes the ability to use UV light to break down organic compounds by photo catalytic degradation



Description of test: Self cleaning capabilities were tested using FTIR analysis. An organic soiling compound is applied to the glass, and with exposure to UV light the substance is decomposed into CO_2. Performance is assessed by comparing the slope of the lines in the dark versus that subjected to light.

MADISON AREA | TECHNICAL COLLEGE

Renewable Energy Certificate

Renewable Energy Certificate Requirements

Take these core classes			
Intro to Renewable Energy	(20-806-291)	Fall	3 credits
Solar Photovoltaic Technology #	(20-806-292)	Spring	3 credits
Plus additional coursework from this list as needed to reach at least 9 credits total			
RE for International Development	(20-806-290)	Summer Study Abroad	3 credits
Solar Photovoltaic Installation Lab *	(20-806-293)	Summer	1 credit
Renewable Energy Honors Project	(20-806-807)	Fall or Spring	2-3 credits
Renewable Energy Electives *	(20-806-xxx)		1-3 credits
Energy and Society ‡	(20-809-269)	Spring	3 credits
		TOTAL CREDITS	**at least 9**

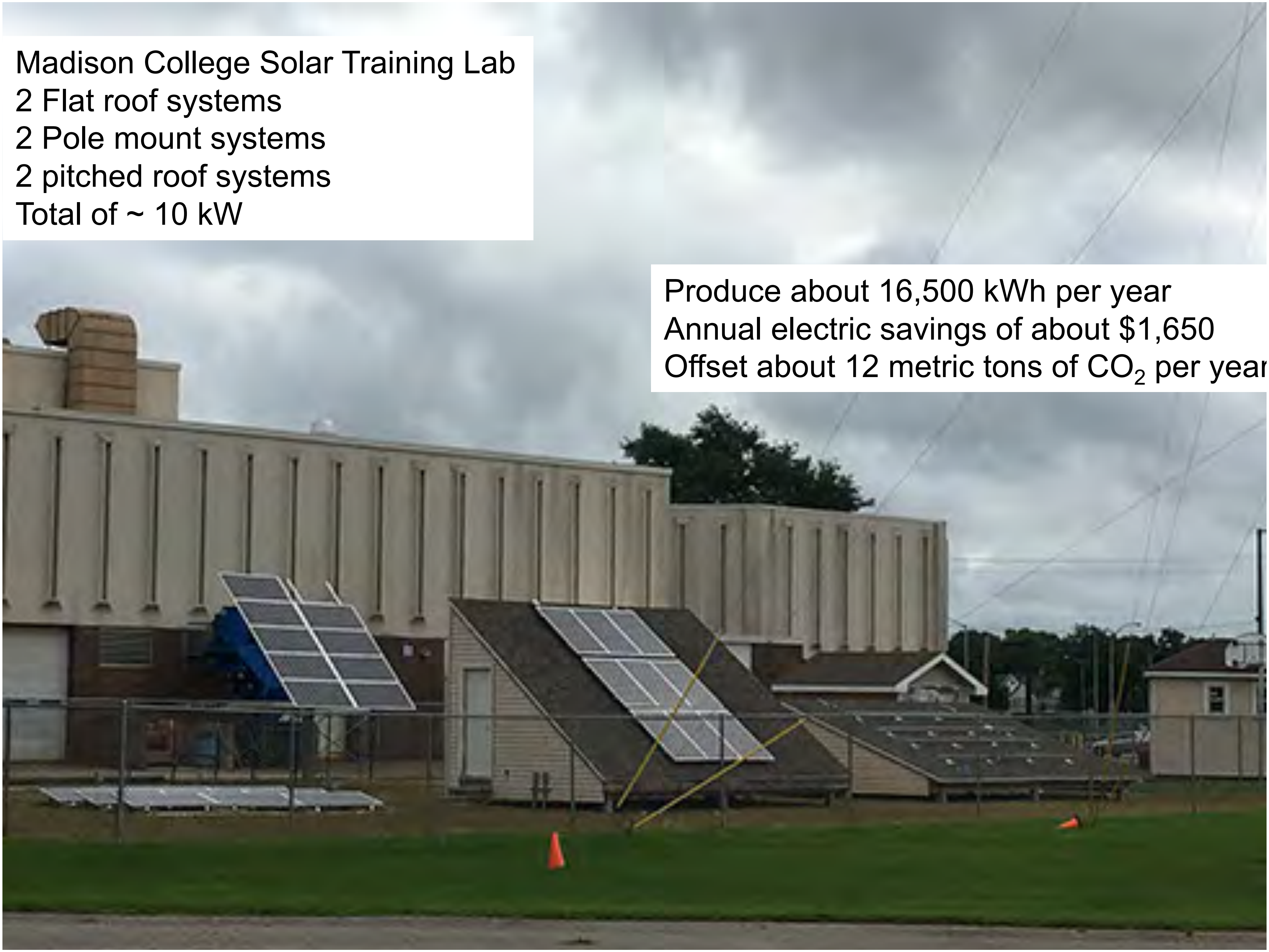
Students completing this course will be qualified to take the examinations required to earn NABCEP and ETA solar industry certifications.

* Co/Pre-requisite knowledge or experience is required in electricity/ electronics/ electrical circuits.

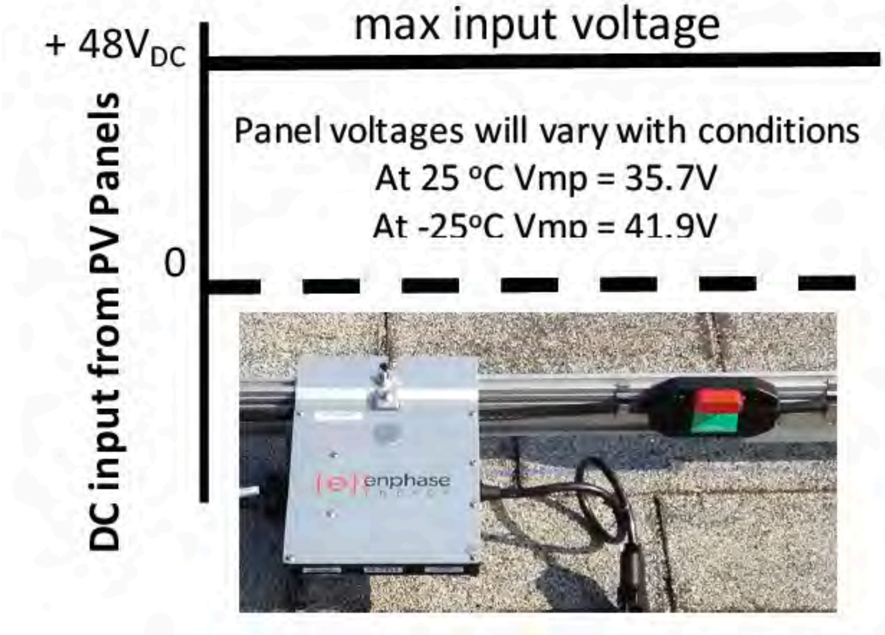
‡ This course satisfies social sciences requirements for many four-year universities.

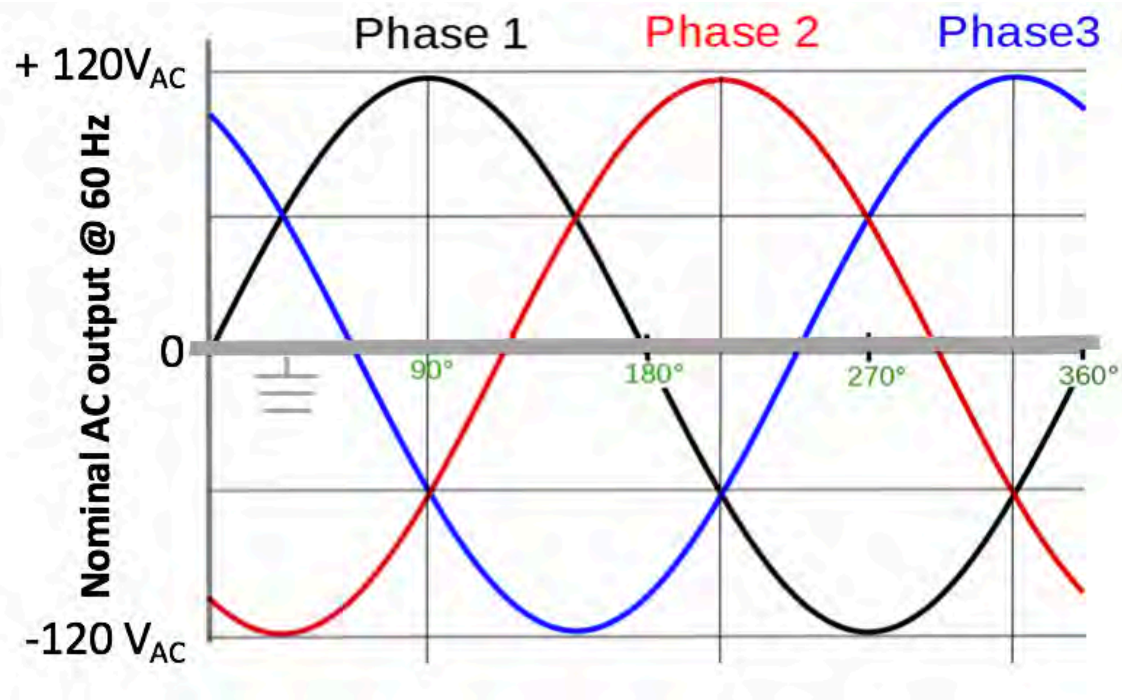
Madison College Solar Training Lab
2 Flat roof systems
2 Pole mount systems
2 pitched roof systems
Total of ~ 10 kW

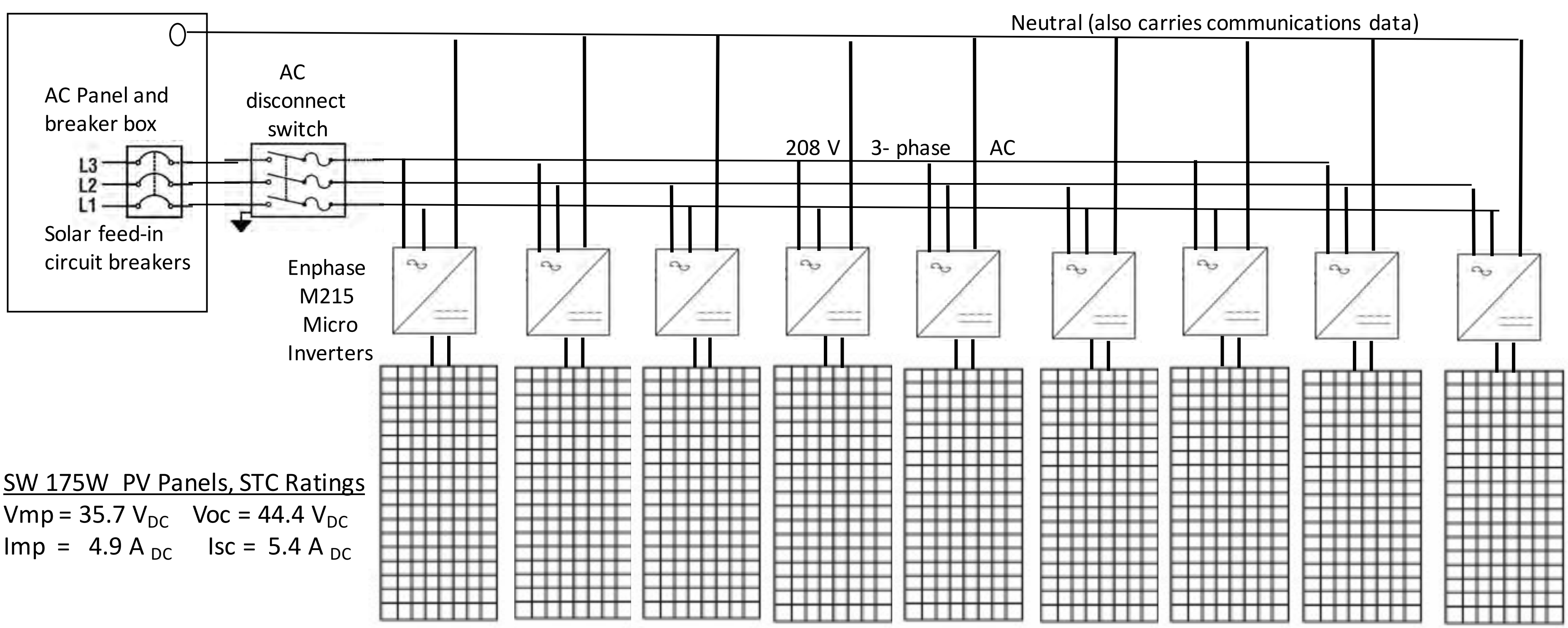
Produce about 16,500 kWh per year
Annual electric savings of about $1,650
Offset about 12 metric tons of CO_2 per year



System Design:





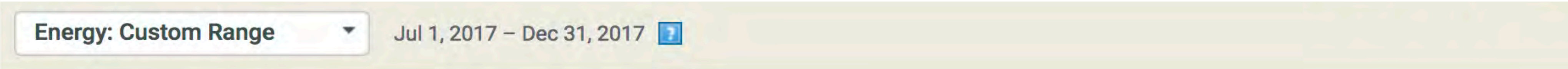


SW 175W PV Panels, STC Ratings

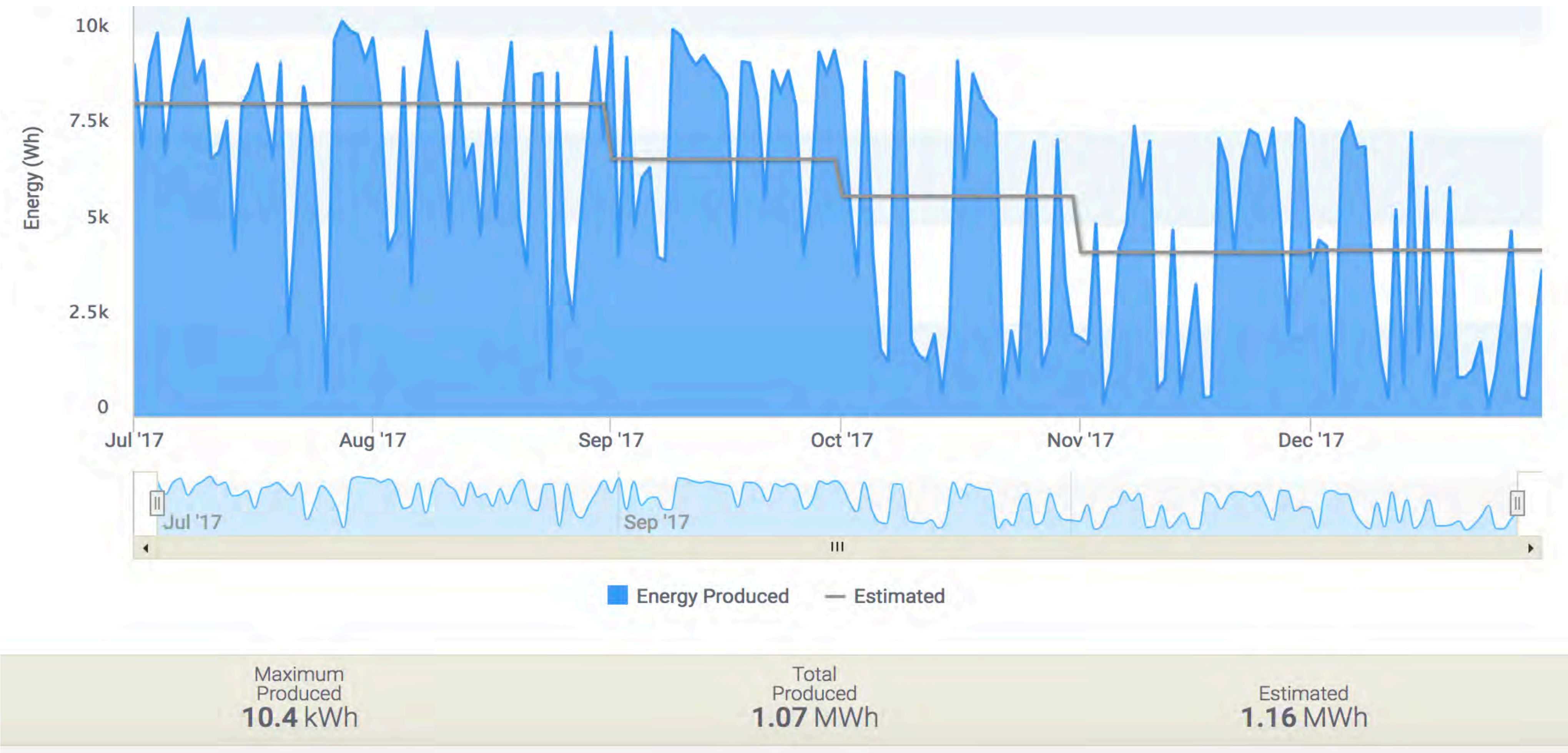
Vmp = 35.7 V_{DC} Voc = 44.4 V_{DC}

Imp = 4.9 A_{DC} Isc = 5.4 A_{DC}

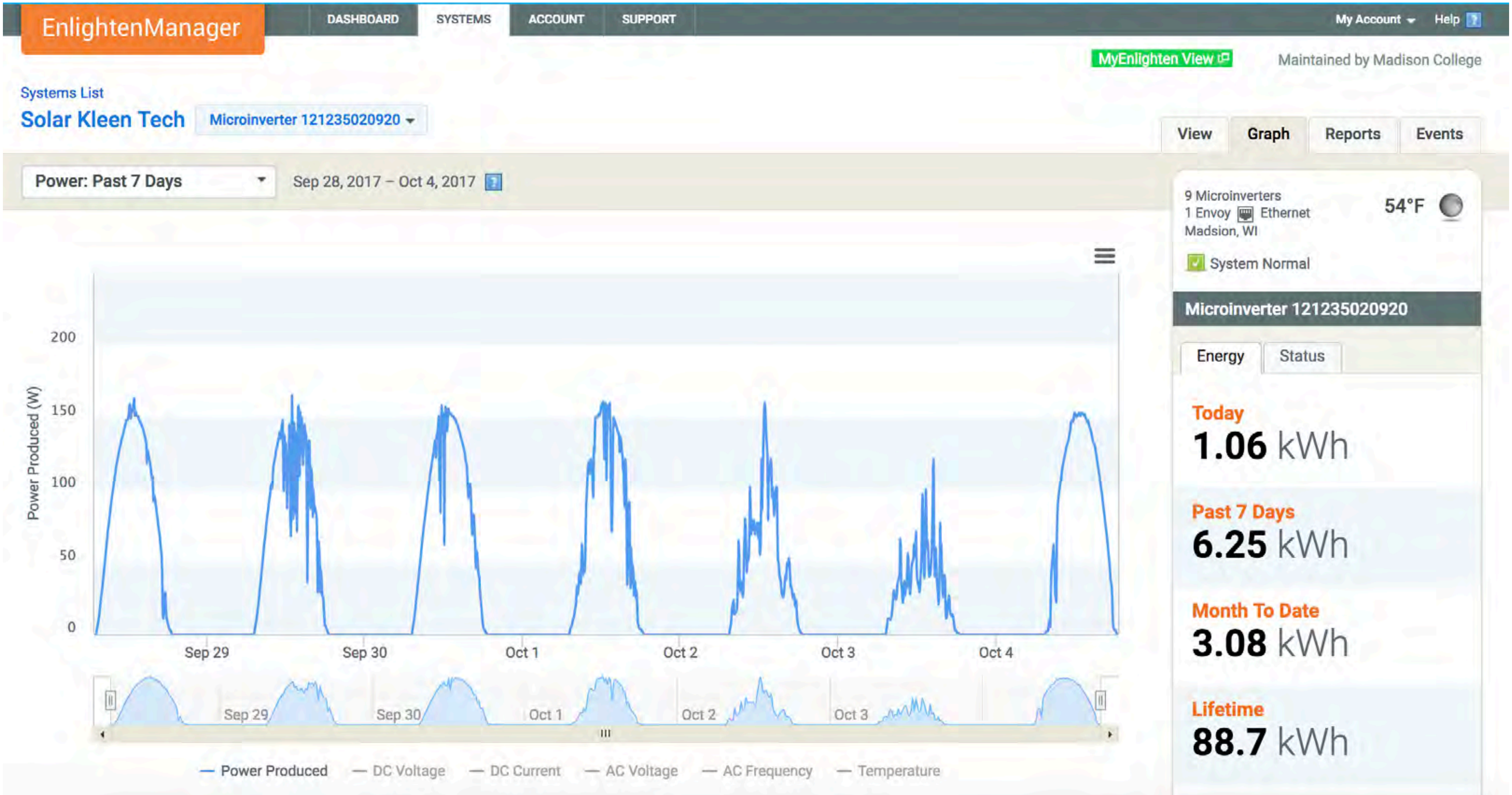
System Output:



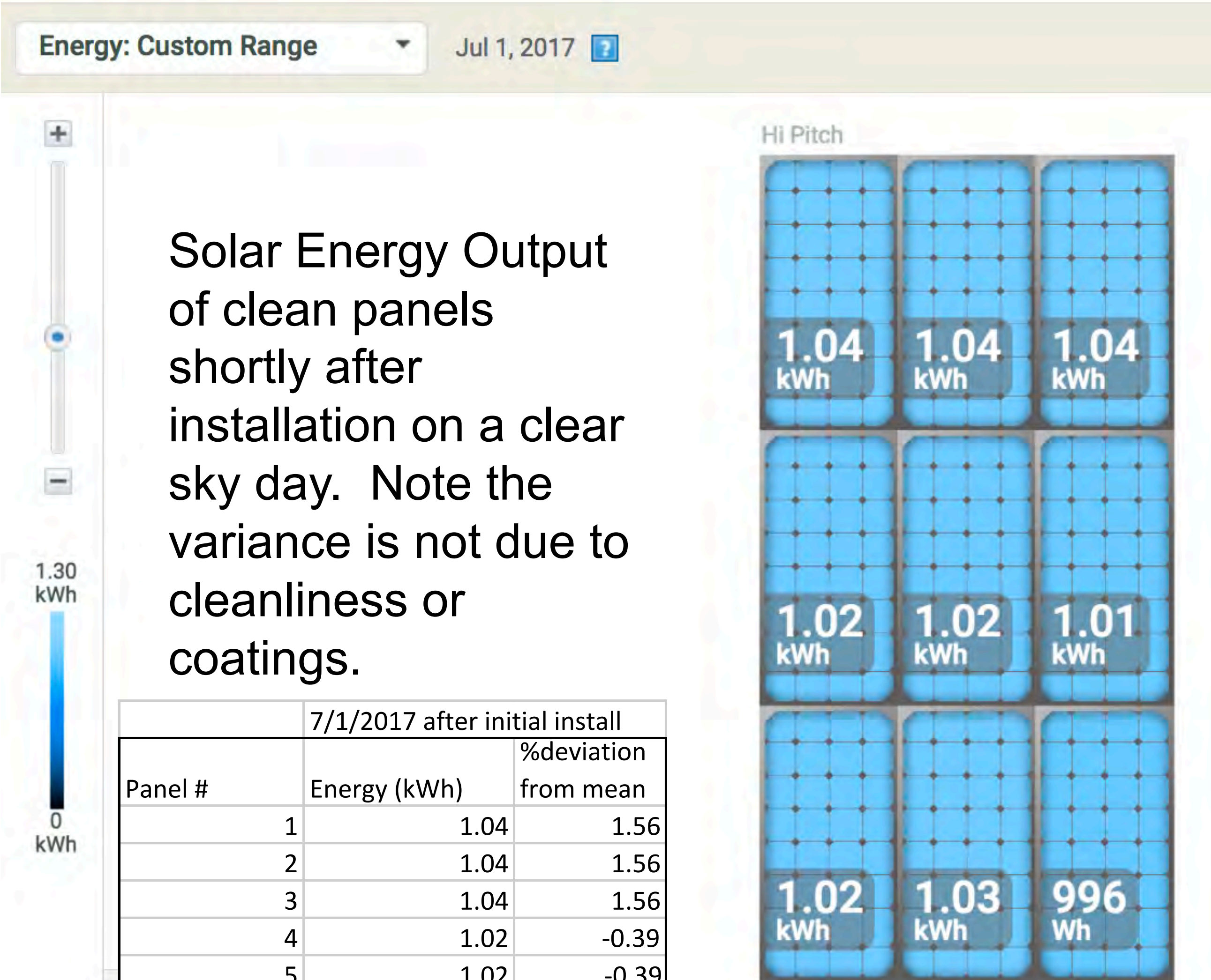
System output for Q3 and Q4 of 2017. Note variation on both daily and season basis. Total energy produced by the system was 92% of that predicted values based on system components and 30 year climactic data, indicating that all of the various system components are functioning as expected.



System Output:



System Output:



Solar Energy Output of clean panels shortly after installation on a clear sky day. Note the variance is not due to cleanliness or coatings.

	7/1/2017 after initial install	
Panel #	Energy (kWh)	%deviation from mean
1	1.04	1.56
2	1.04	1.56
3	1.04	1.56
4	1.02	-0.39
5	1.02	-0.39
6	1.01	-1.37
7	1.02	-0.39
8	1.03	0.59
9	0.996	-2.73
Mean	1.024	
StDev	0.015	
Relative StDev	0.015	

Note the top row outperforms the middle, which outperforms the bottom. This is likely a result of height above the horizon, and the slightly longer day length for the upper panels relative to those below.

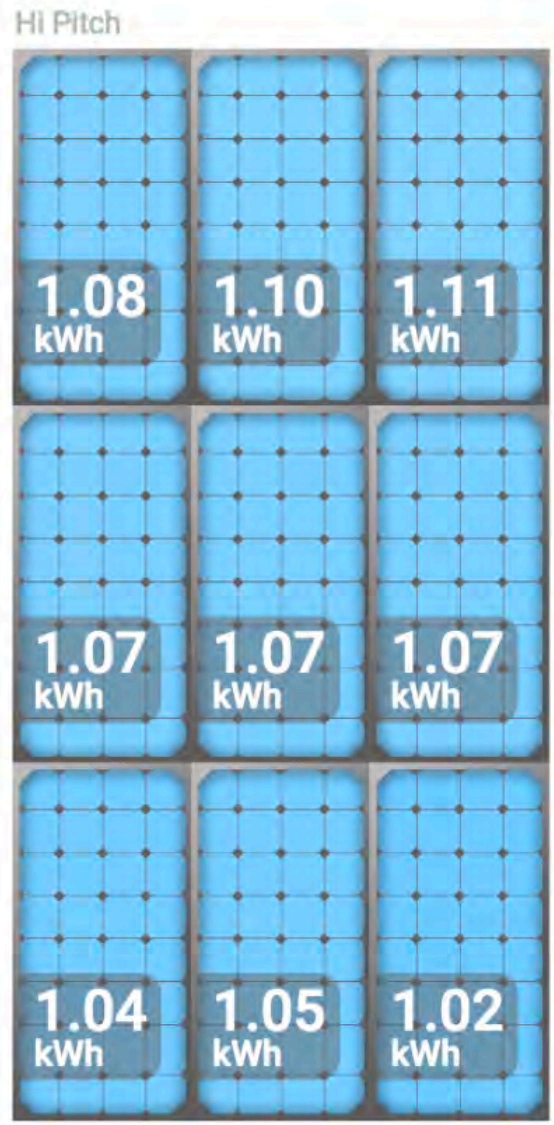
System Output:

Energy: Custom Range

Sep 30, 2017

Daily Output shortly before coating application on a clear sky day, roughly 16 weeks after initial installation of panels. Note the deviation has roughly doubled. This is likely due to soiling.

	9/30/2017 before coating	
Panel #	Energy (kWh)	%deviation from mean
1	1.08	1.14
2	1.1	3.02
3	1.11	3.95
4	1.07	0.21
5	1.07	0.21
6	1.07	0.21
7	1.04	-2.60
8	1.05	-1.66
9	1.02	-4.47
Mean	1.068	
StDev	0.028	
Relative StDev	0.026	



System Output:

Energy: Custom Range

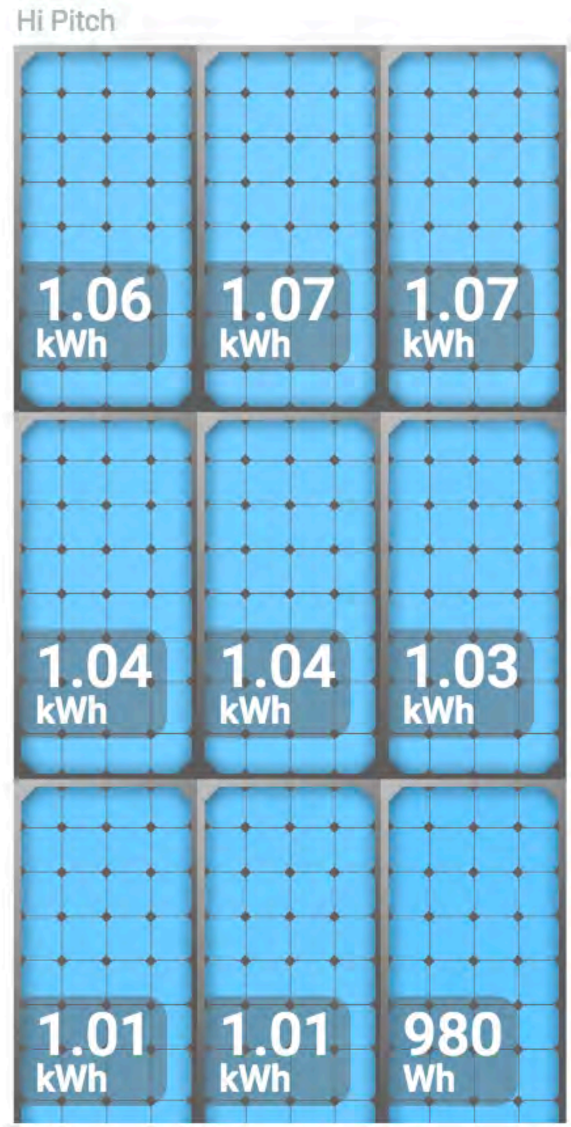
Oct 4, 2017

1.30 kWh

0 kWh

Daily Output after coating on a clear sky day. Note that the coatings do not appear to have reduced the output or altered the deviation among panels.

	10/04/17 after coating	
Panel #	Energy (kWh)	%deviation from mean
1	1.06	2.47
2	1.07	3.44
3	1.07	3.44
4	1.04	0.54
5	1.04	0.54
6	1.03	-0.43
7	1.01	-2.36
8	1.01	-2.36
9	0.98	-5.26
Mean	1.034	
StDev	0.030	
Relative StDev	0.029	



System Output:

Energy: Custom Range

Jan 13, 2018

Daily Output after coating on a clear sky day in January. Note, the day length is now quite short, so energy outputs are lower across the board.

	1/13/18	
Panel #	Energy (kWh)	%deviation from mean
1	0.926	0.96
2	0.944	2.92
3	0.945	3.03
4	0.908	-1.01
5	0.929	1.28
6	0.917	-0.02
7	0.898	-2.10
8	0.904	-1.44
9	0.884	-3.62
Mean	0.917	
StDev	0.021	
Relative StDev	0.023	

System Output:

Energy: Today

Feb 6, 2018

1.20 kWh

0 kWh

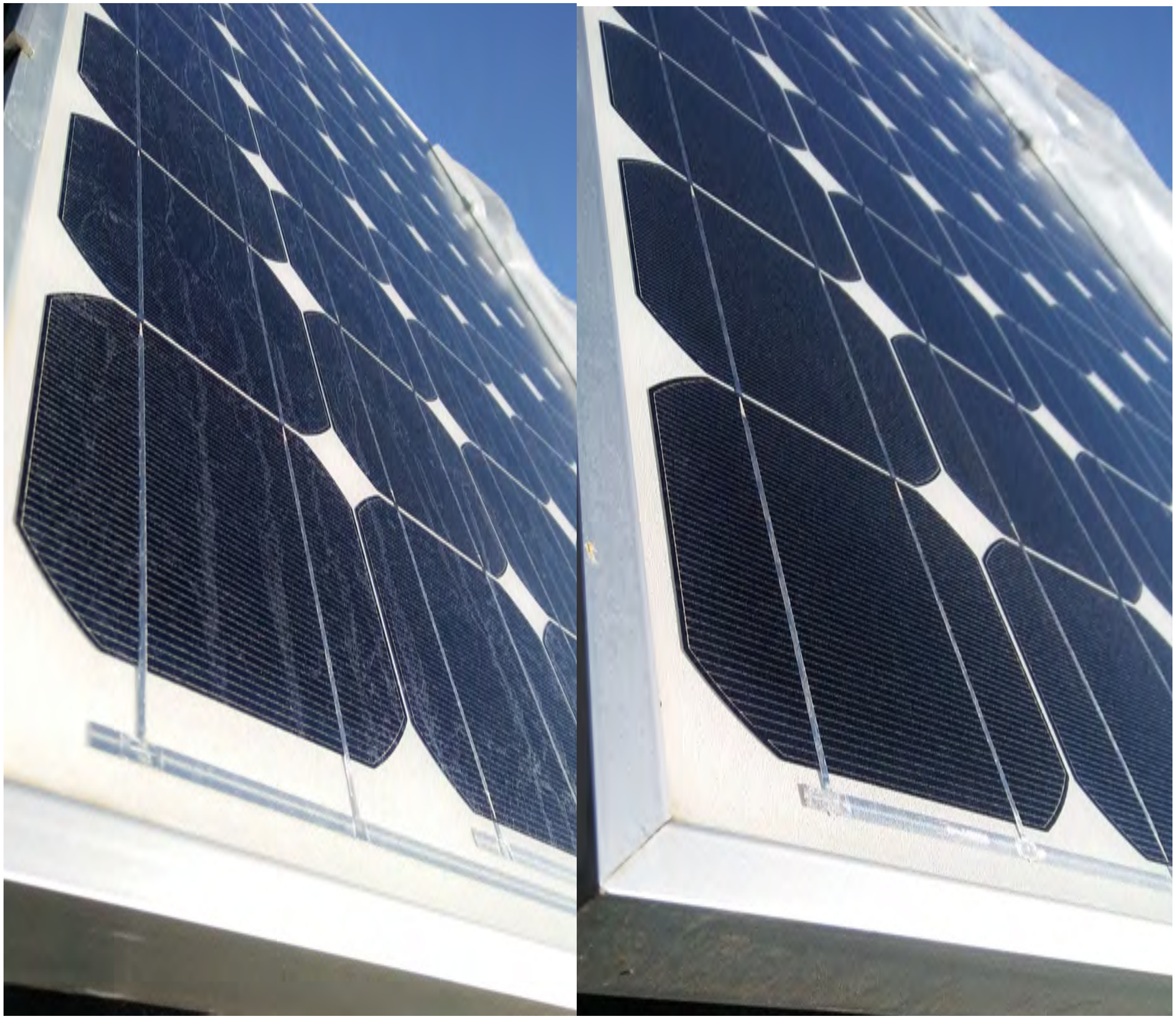
Daily Output for a clear sky day following a 6 inch snowstorm. Panels were covered in snow.

Panel #	Energy (kWh	%deviation from mean
1	0.049	32.43
2	0.048	29.73
3	0.046	24.32
4	0.034	-8.11
5	0.026	-29.73
6	0.029	-21.62
7	0.032	-13.51
8	0.031	-16.22
9	0.038	2.70
Mean	0.037	
StDev	0.009	
Relative StDev	0.234	

Lessons learned from the field tests?

Challenge: Coating Panels on a sloped roof is tough!

Challenge: Much like paint, spray coating panels requires training and practice - streaking can be an issue



Photos of coated solar panels. Note the undesirable streaking on the left of the first panel coated, and the barely distinguishable properly coated panel on the right after the application technique had been mastered

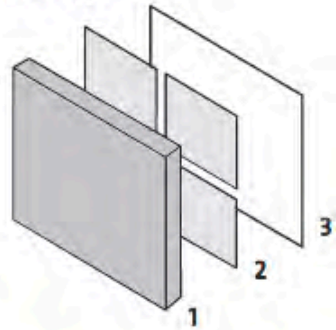
Challenge: Overspray is an issue for coating panels. Wind can be especially problematic!

Challenge: Measuring coating effectiveness in the field is difficult, due to variability among panels

SOLARWORLD

SolarWorld Module SW 165/175/185 mono

Design



1] Front: tempered glass
2] 72 monocrystalline solar cells 125 mm x 125 mm embedded in EVA (ethylene-vinyl-acetate)
3] Rear: Tedlar foil

Performance under standard test conditions (STC)

Peak power (Pmax)	165 Wp	175 Wp	185 Wp
Maximum power point voltage (Vmpp)	35.3 V	35.7 V	36.0 V
Maximum power point current (Impp)	4.7 A	4.9 A	5.1 A
Open circuit voltage (Voc)	44.1 V	44.4 V	44.5 V
Short circuit current (Isc)	5.2 A	5.4 A	5.5 A

Performance at 800 W/m², NOCT, AM 1.5

Peak power (Pmax)	125 Wp	131 Wp	138 Wp
Maximum power point voltage (Vmpp)	32.7 V	33.1 V	33.4 V
Maximum power point current (Impp)	3.8 A	4.0 A	4.1 A
Open circuit voltage (Voc)	40.9 V	41.1 V	41.2 V
Short circuit current (Isc)	4.2 A	4.4 A	4.5 A

Minor reduction in efficiency under partial load conditions at 25°C: at 200 W/m², 95 % (+/- 3 %) of the STC efficiency (1000 W/m²) is achieved.

Component materials

Cells per module	72
Solar cells	monocrystalline silicon
Cell dimensions	125 x 125 mm

Thermal characteristics

NOCT	46°C
TK Isc	0.06 %/K
TK Voc	-0.35 %/K

System design characteristics

Maximum system voltage	715 V
Reverse current load	Do not apply external voltages in excess of Voc to the module

Rated power and maximum tolerance

Rated power	165/175/185 Wp +/- 3 %

Analysis of Co-Variance

Dependent Variable	**= f (Covariate**	**+**	**Independent Variable)**
Energy Output after Coatings were applied	Energy Output before coatings were applied		Coated vs Uncoated

Model parameters (Energy after coating):

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Intercept	-52.943	73.522	-0.720	0.499	-232.845	126.959
Energy before coating	2.705	0.939	2.880	**0.028**	0.407	5.004
Treatment-Coated	-2.180	1.960	-1.112	0.309	-6.976	2.617
Treatment-Uncoated	0.000	0.000				

Equation of the model (Energy after coating):

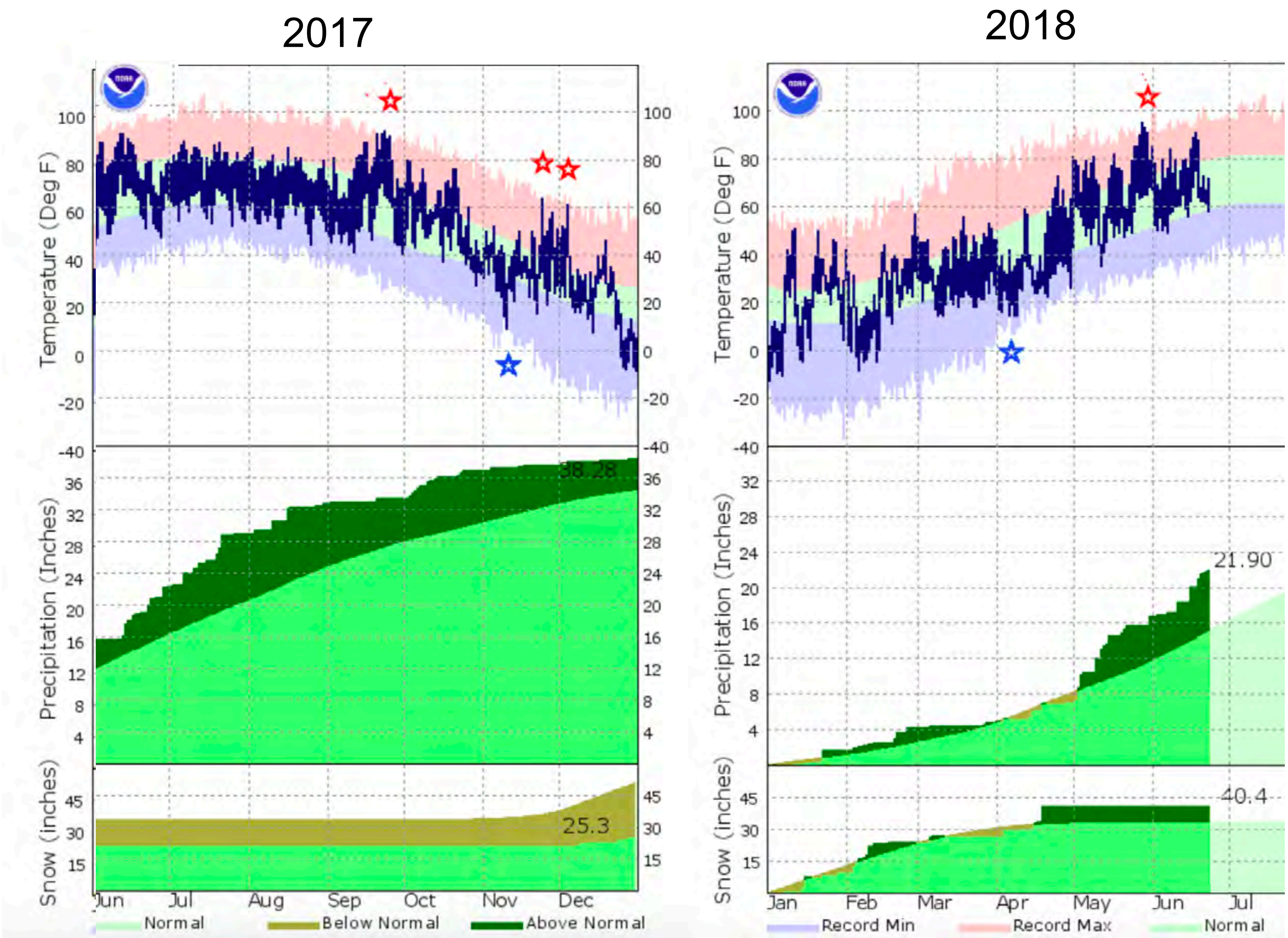
Energy after coating = -52.9432855280306+2.70534550195566*Energy before coating-2.17992177314213*Treatment-Coated

The p-value for the effect of the energy produced before coating is small (0.028) indicating that the difference between individual panels was the primary factor explaining differences in performance after the coatings were applied.

The p-value for the effect of the coating is large (0.309) and the upper and lower bounds for the effect of coating include 0. Thus, we cannot conclude that there is any significant difference between the coated and uncoated panels.

Challenge: Field Tests depend on weather!

Madison, WI Climatological data – 2017-2018



This past year has been very wet – not much opportunity for the panels to soil !

What else does the college have in the works?

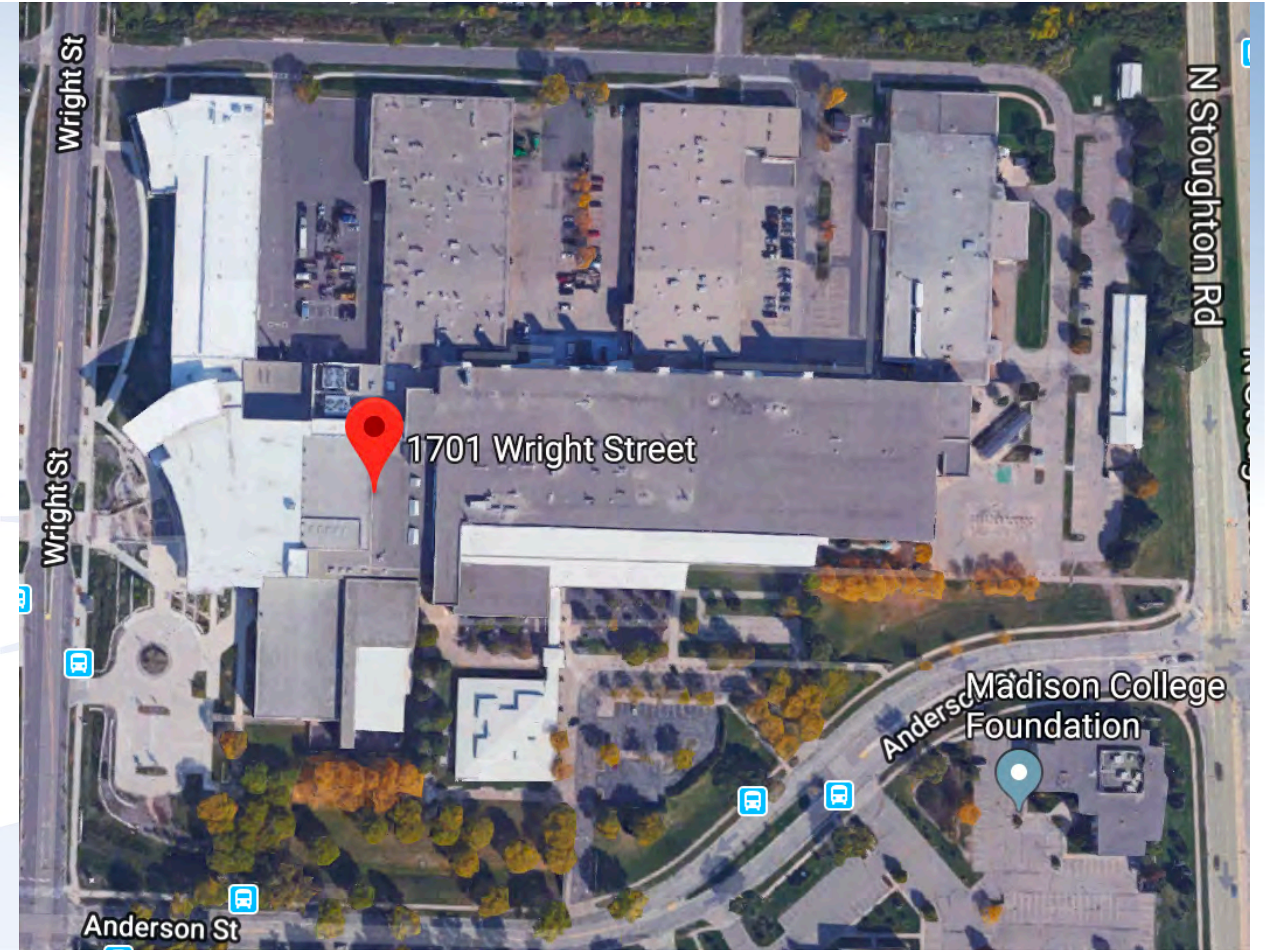
American School&University

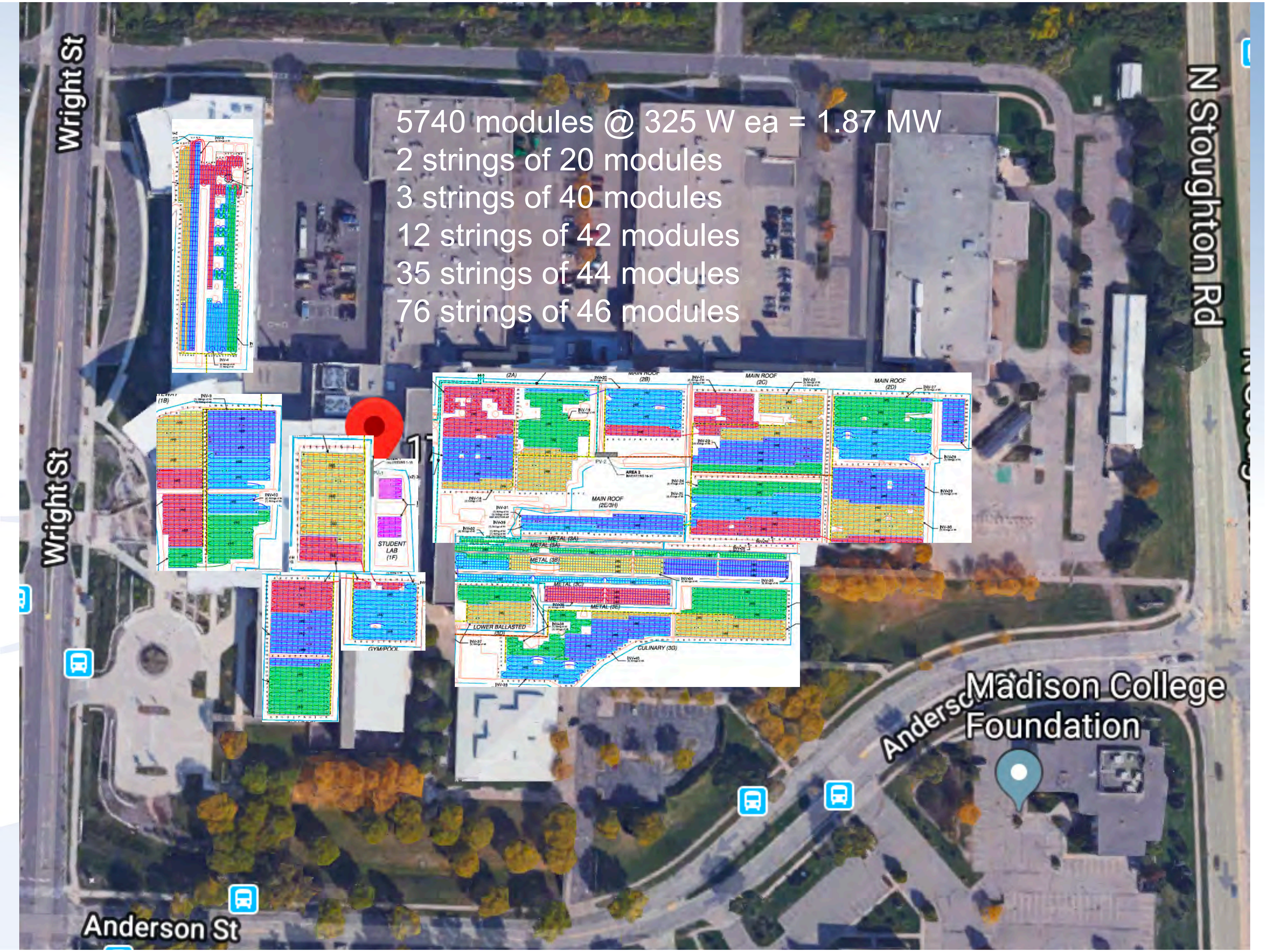
GREEN > SUSTAINABILITY INITIATIVES

Madison, Wis., community college is installing state's largest rooftop solar system

The array at Madison Area Technical College will consist of 5,250 photovoltaic panels.

Mike Kennedy | Jun 20, 2018


Wright St
Wright St
N Stoughton Rd
1701 Wright Street
Madison College
Foundation
Anderson St


5740 modules @ 325 W ea = 1.87 MW
2 strings of 20 modules
3 strings of 40 modules
12 strings of 42 modules
35 strings of 44 modules
76 strings of 46 modules
Wright St
Wright St
N Stoughton Rd
Anderson St
Madison College Foundation
MAIN ROOF (2E/3H)
STUDENT LAB (1F)
GYM/POOL
CULINARY (3G)

Take Home Points

- Working with small businesses and start-up companies offers unique learning for students
- Honors/ Independent study projects allow for learning outside of ordinary curriculum
- Undergraduate research is incredibly motivating for students
- Field application of solar panel coatings has many challenges
- Field validation of solar panel coatings is difficult – will require large data sets, robust baseline data, and long term trials over extended periods of time

Thank you for your attention!

Questions?

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Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.