NREL
Transforming ENERGY

Field & modeling perspectives

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hybrid bifi PV workshop 2022
Ankara, Türkiye

Agenda

1. Our bifacial field and how and why it's setup
2. Findings on technology performance and degradation
3. Findings on rear-irradiance sensor positioning
4. Cool experiments going on: Albedo optimization & AgriPV

Open-source DATA

75 kW bifacial HSAT

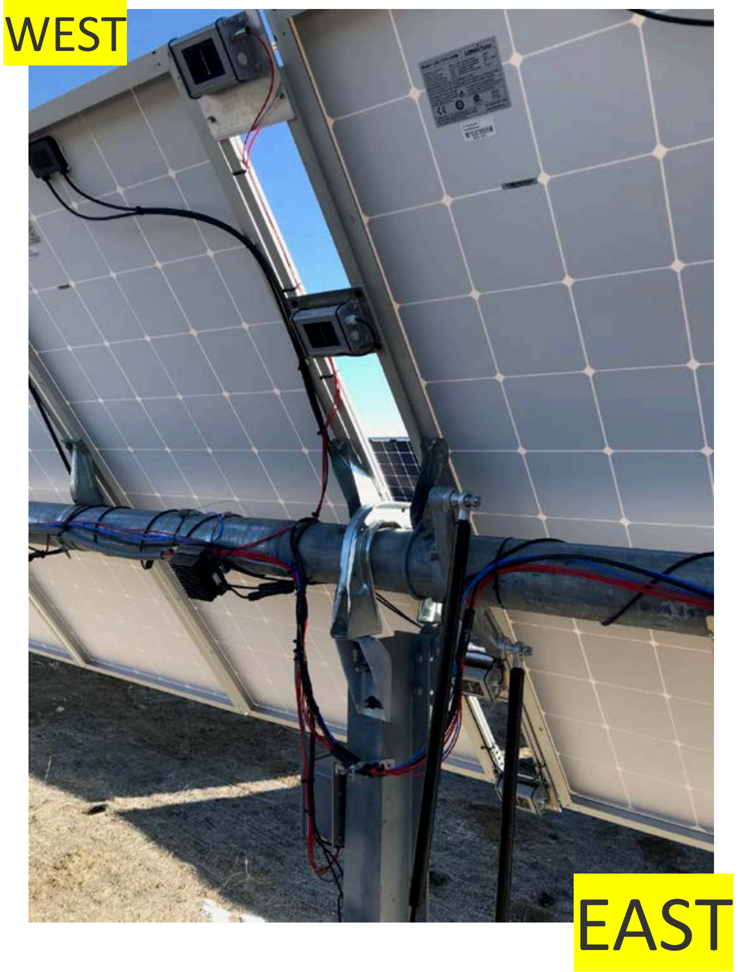
5 bifacial technologies

3 years of open-source data

https://datahub.duramat.org/dataset/best-field-data

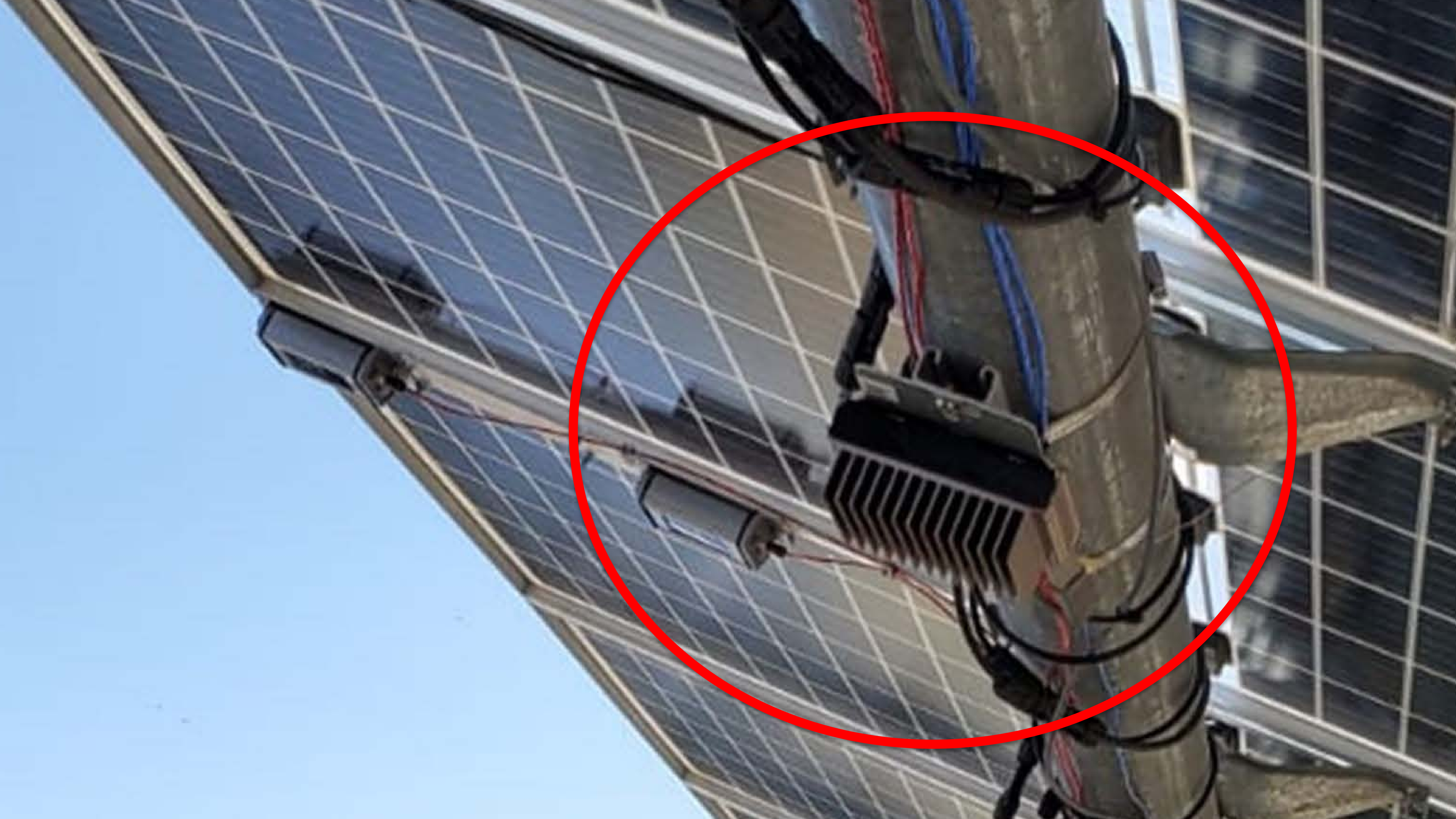
Module and string-level performance data

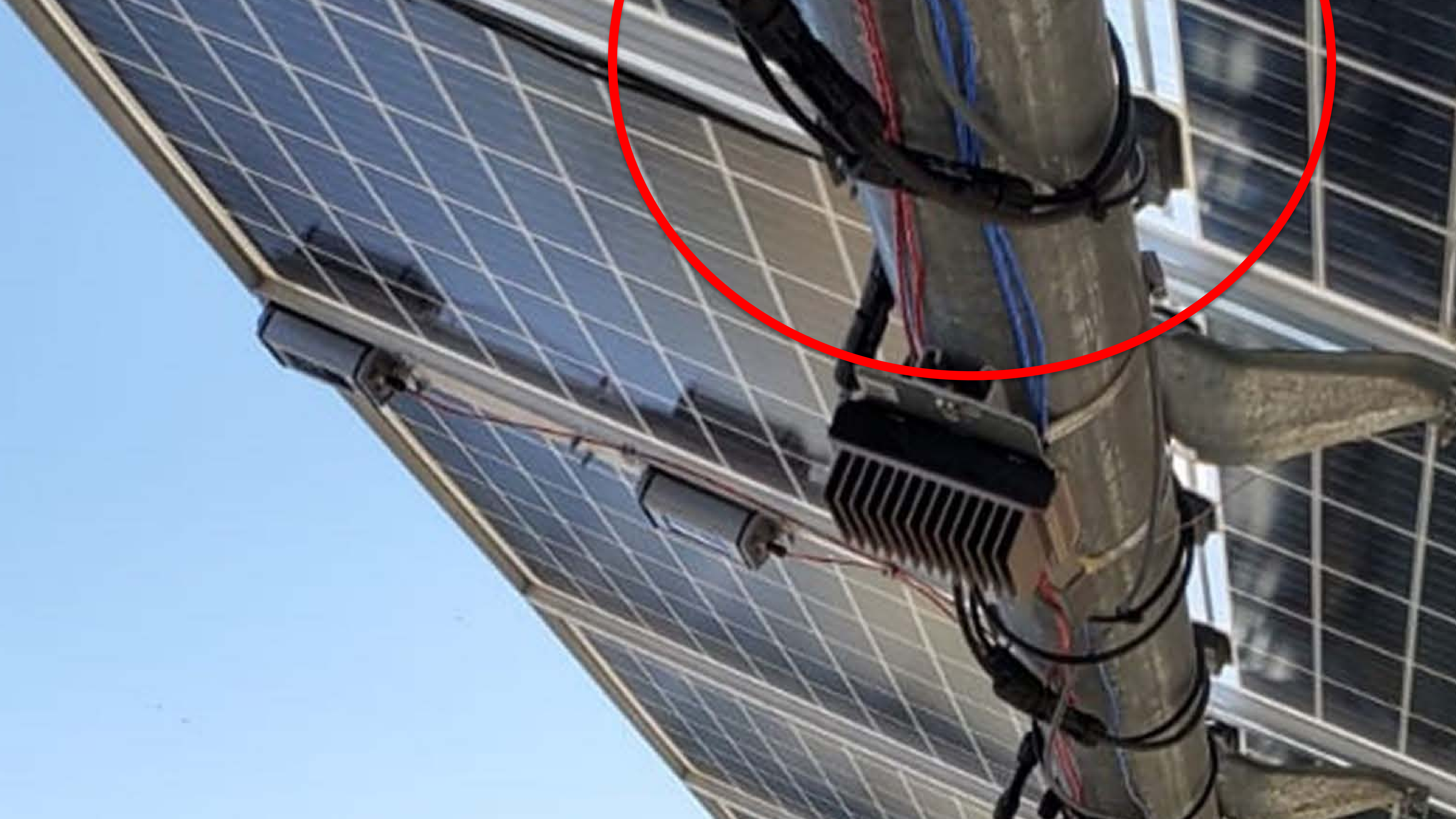
Sensors!

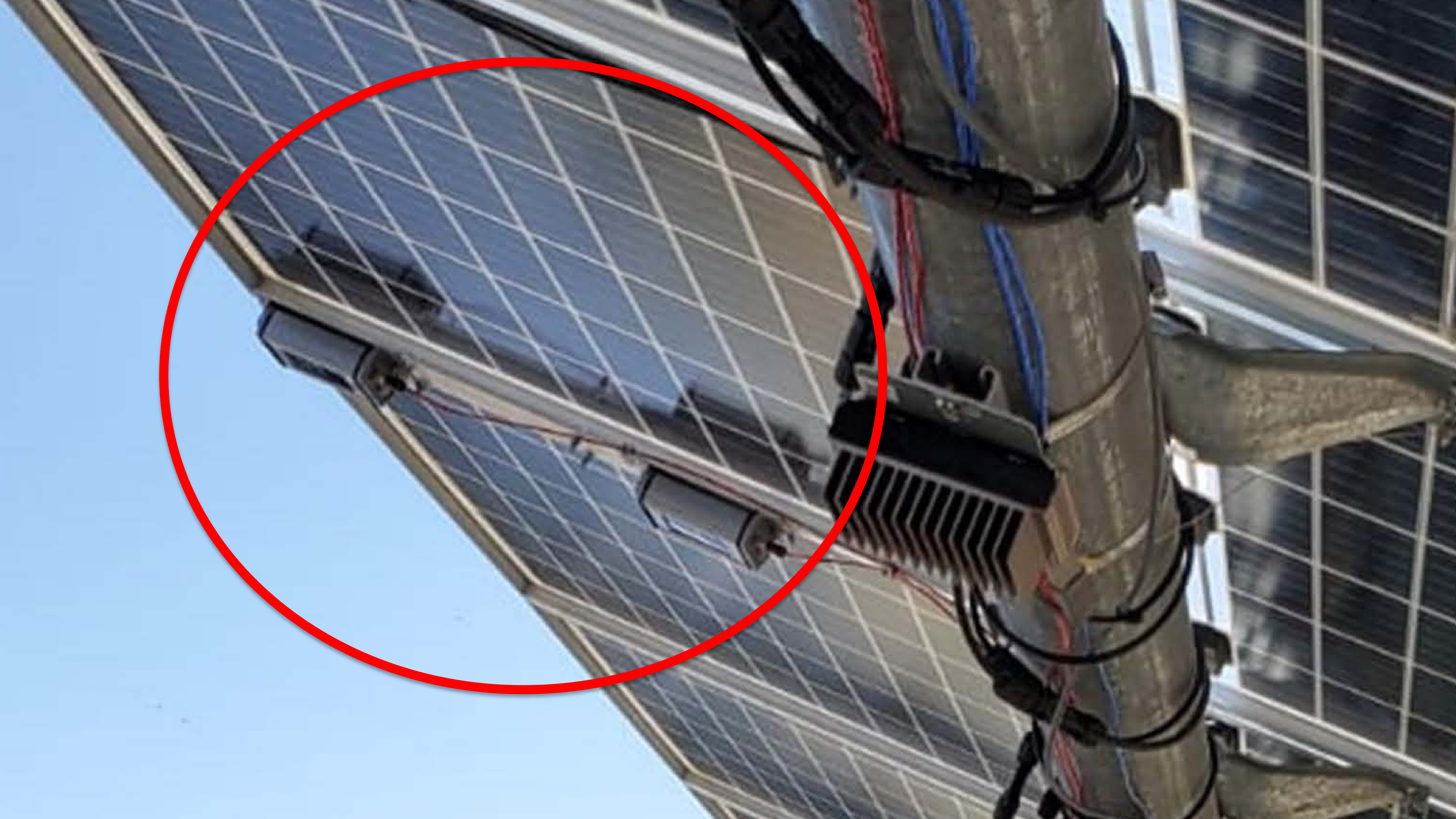


2 Broadband irradiance sensors

4 Reference Cells

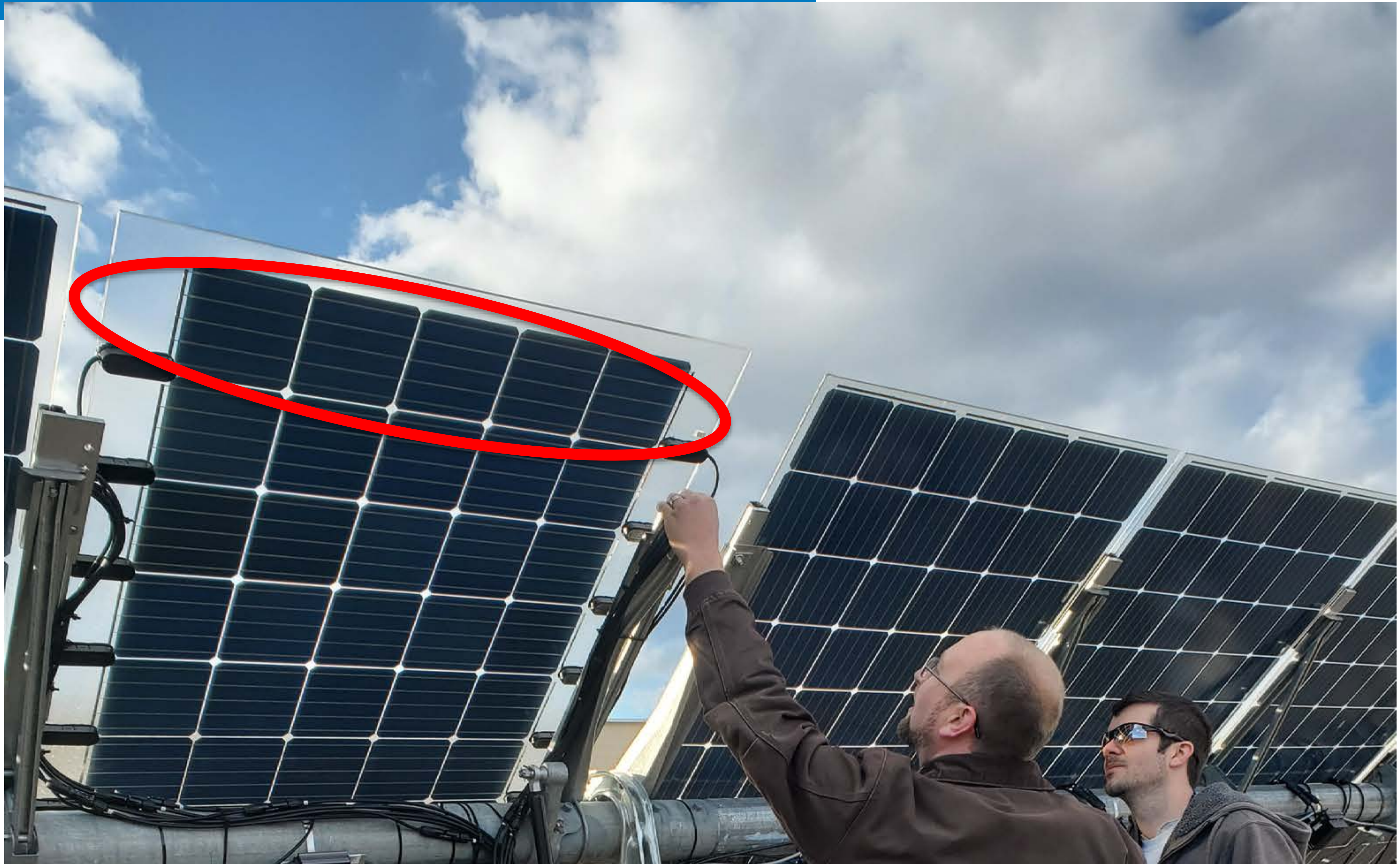






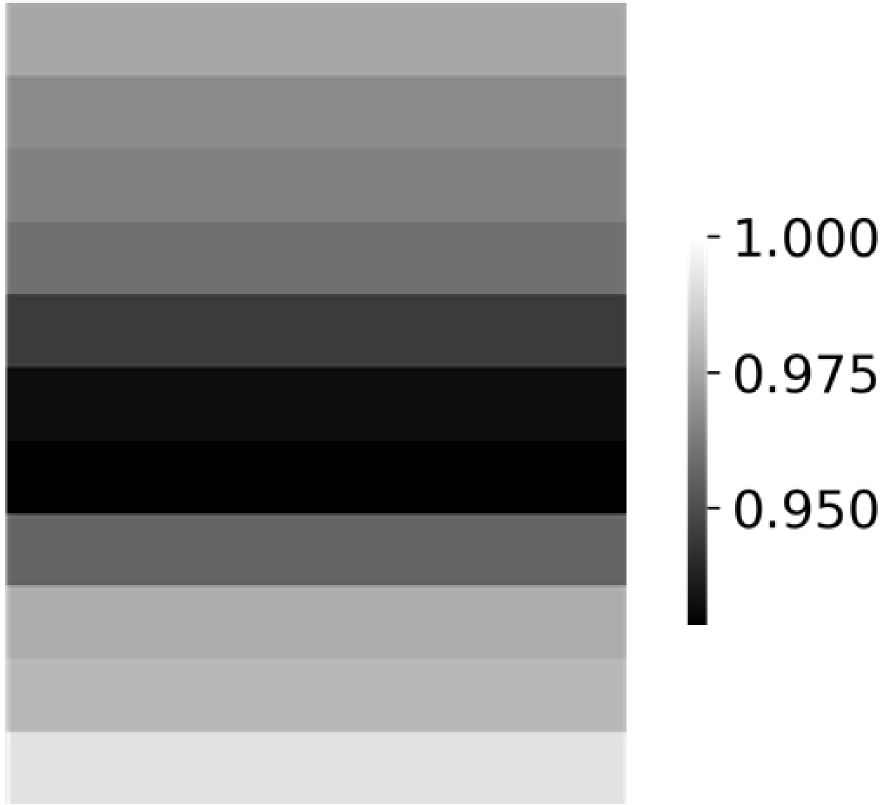
Sensors!

‘Hydra’ module



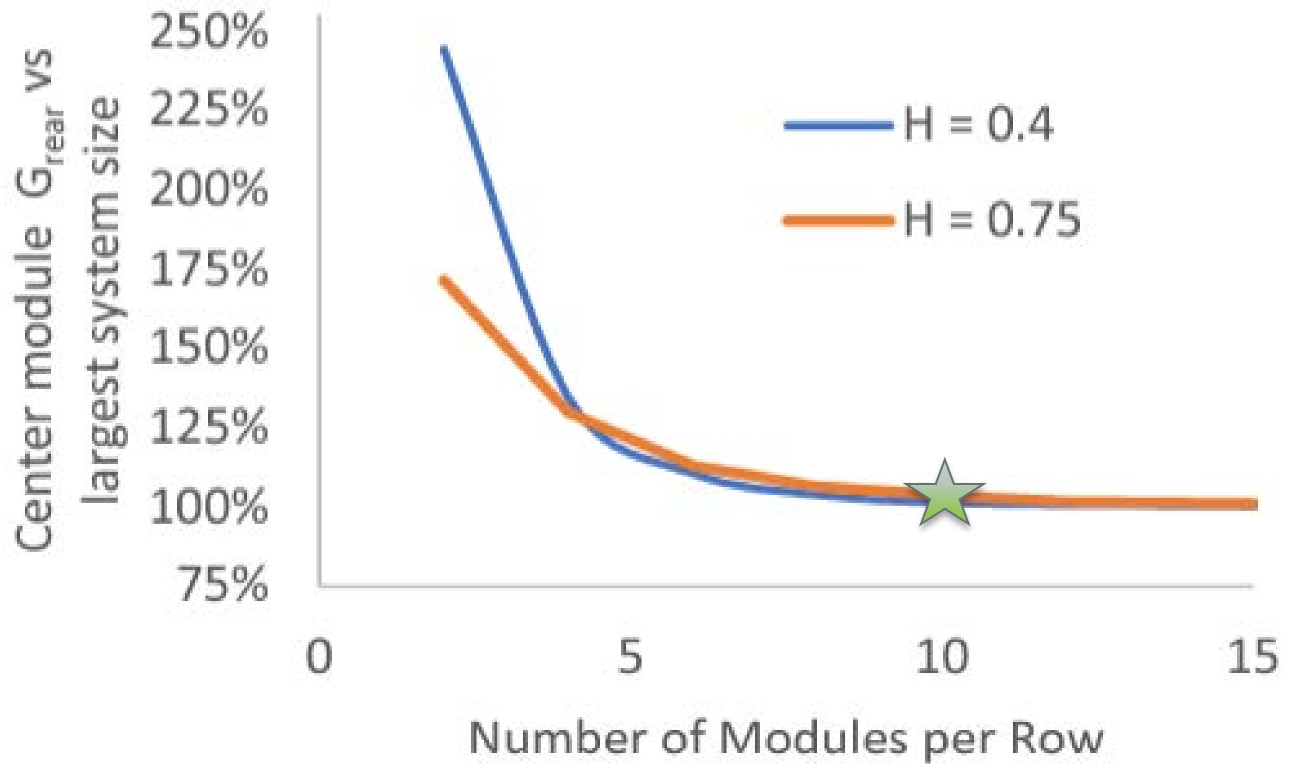
‘Hydra’ module

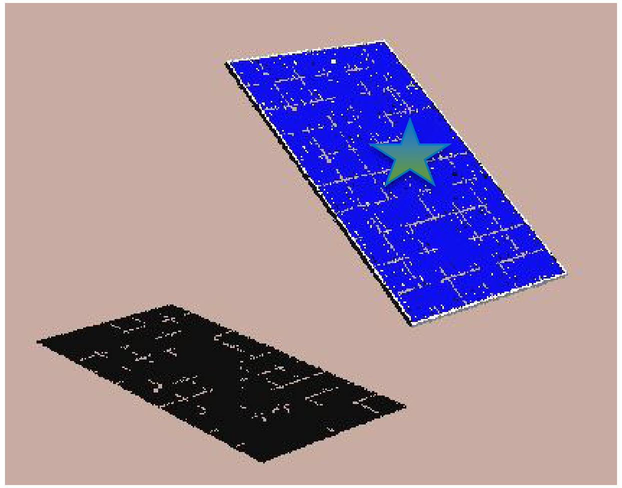
Irradiance variation

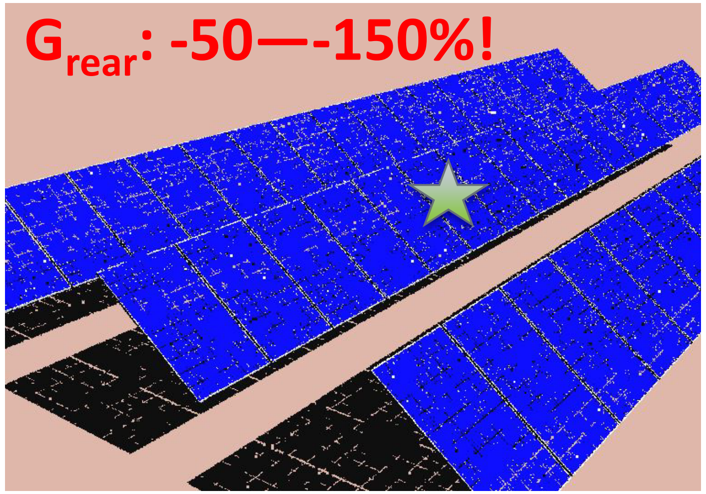


Why 10 rows x 20 modules?

System size for steady-state Rear Irradiance







C. Deline et al., Assessment of Bifacial Photovoltaic Module Power Rating Methodologies – Inside and Out, J. Photovoltaics **7,** 2017
Ovaitt et al, Model and Validation of Single-Axis Tracking with Bifacial PV, JPV 2019. 10.1109/JPHOTOV.2019.2892872

Why bifacial vs monofacial counterpart comparison?

Overall energy gain for a bifacial system is determined by comparing Energy Yield [kWh] for both monofacial and bifacial systems

$$BG[\%] = \left(\frac{Y_{bifacial}}{Y_{monofacial}} - 1\right) \times 100$$

Silfab module photo

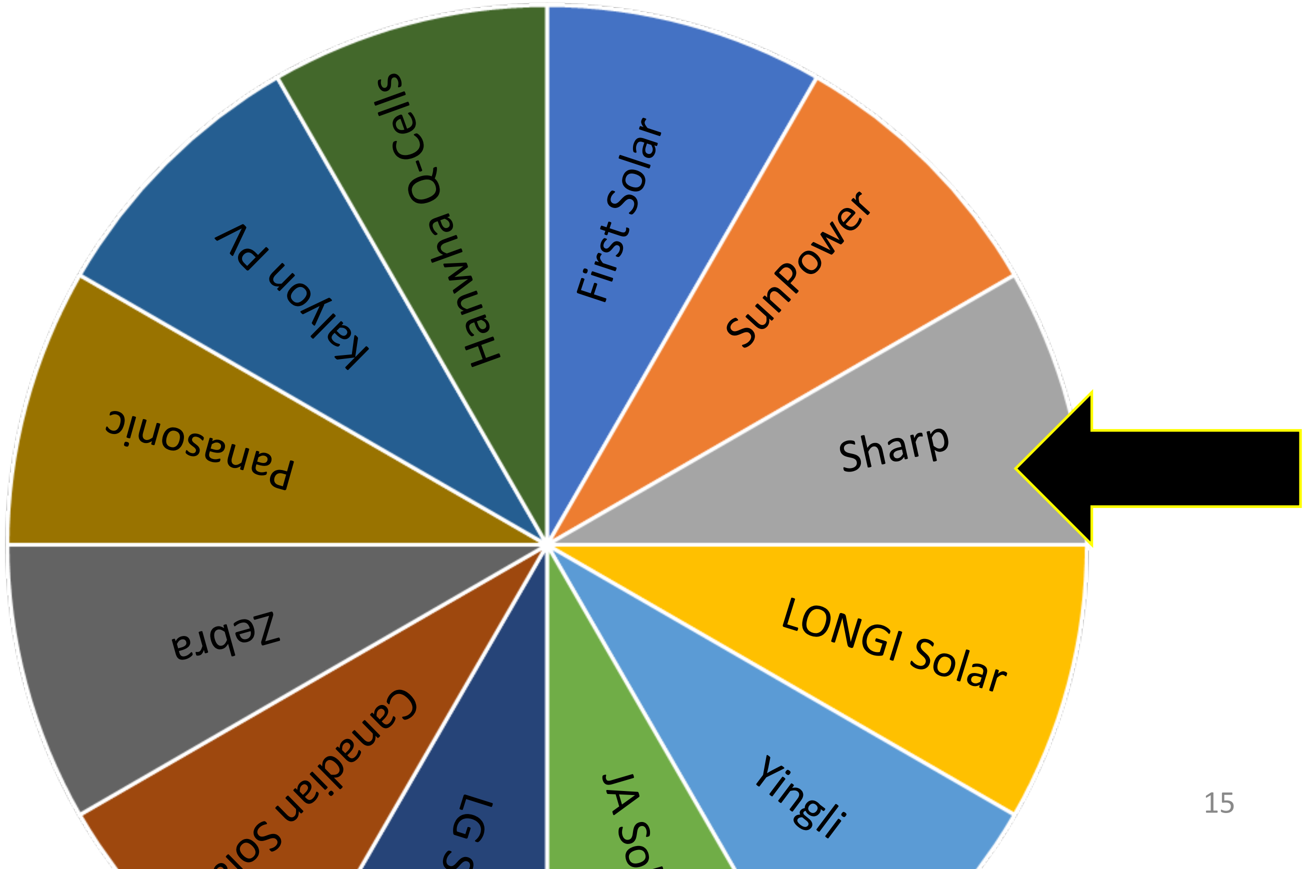
Why bifacial vs monofacial counterpart comparison?

Overall energy gain for a bifacial system is determined by comparing Performance Ratio [kWh/kW] for both monofacial and bifacial systems

$$BG_{Meas} = \left(\frac{PR_{bifi}}{PR_{mono}} - 1 \right) \times 100\%$$

Silfab module photo

VS.



Why bifacial vs monofacial counterpart comparison?

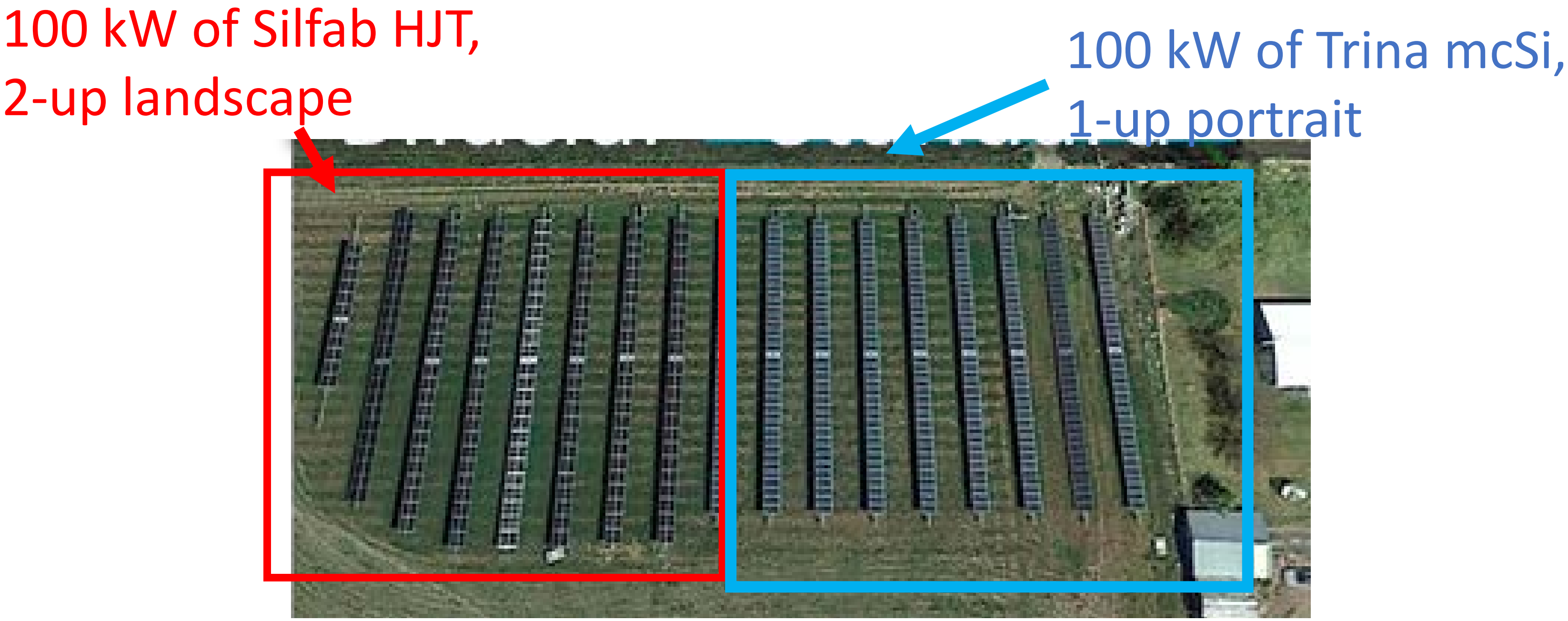
$$BG_{Meas} = \left(\frac{PR_{bifi}}{PR_{mono}} - 1\right) \times 100\%$$

- Difference in module rating
- Temperature coefficient
- Low light dependence
- Mounting orientation
- Bifaciality

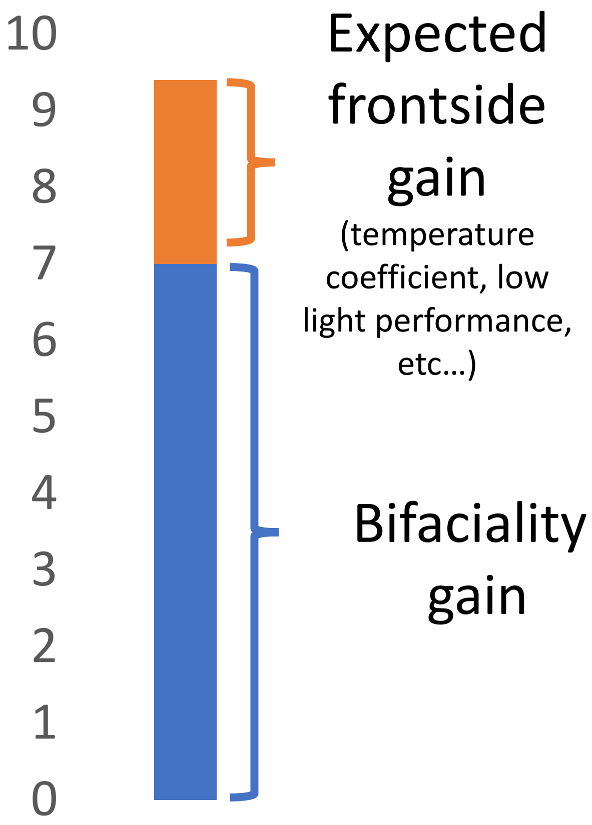
$$BG_{\text{Meas},bifaciality} = \left(\frac{PR_{bifi}}{PR_{mono}} \underbrace{\frac{PR_{mono,model}}{PR_{bifi,model}}}_{\text{Correction Factor}} - 1\right) \times 100\%$$

Ovaitt et al, Model and Validation of Single-Axis Tracking with Bifacial PV, JPV 2019. 10.1109/JPHOTOV.2019.2892872

Why bifacial vs monofacial counterpart comparison?



H = 0.75, GCR = 0.35, Albedo = 0.2 (short grass)



$$BG_{\mathrm{Meas},bifaciality} = \left(\frac{PR_{bifi}}{PR_{mono}} \frac{PR_{mono,model}}{PR_{bifi,model}} - 1 \right) \times 100\%$$

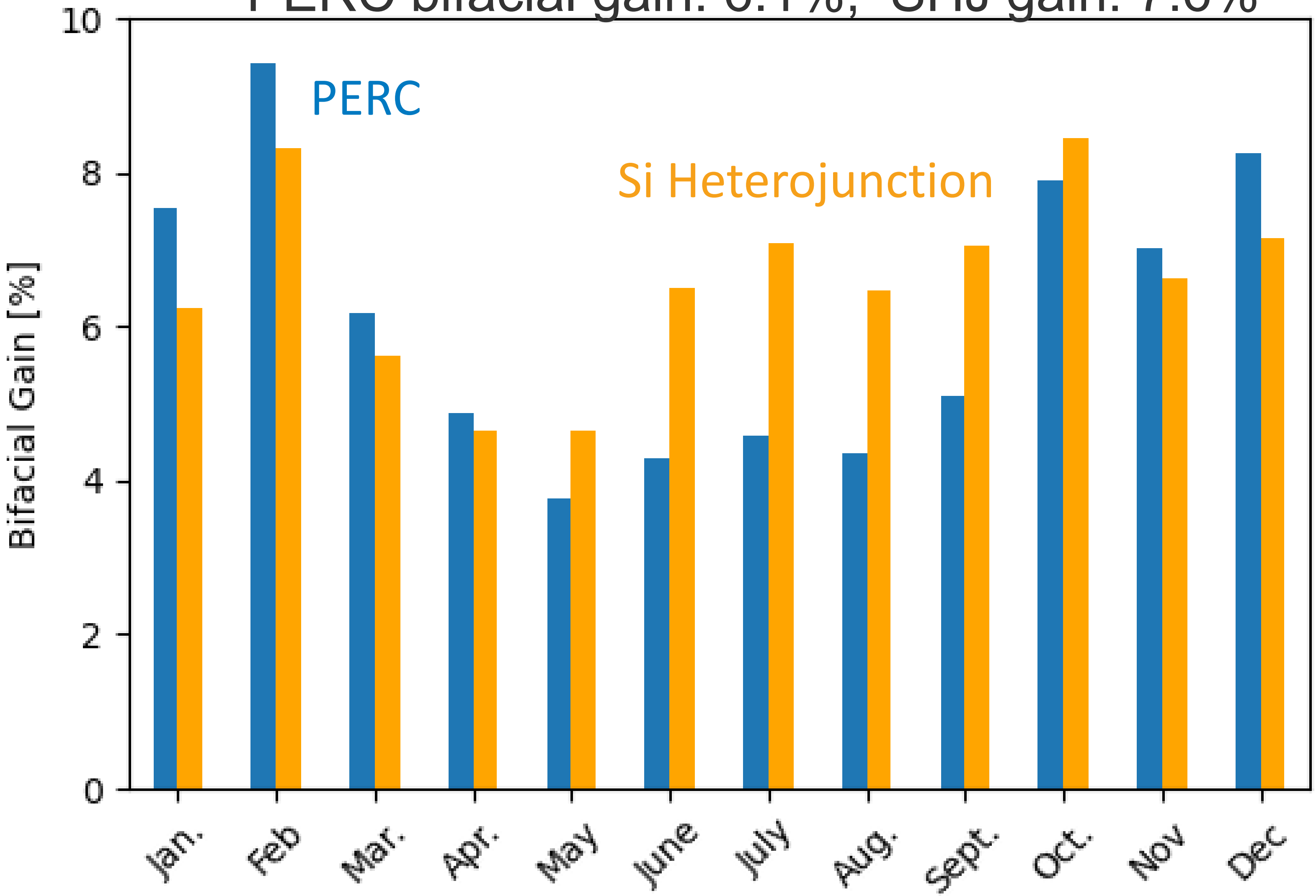
More information on comparing different technologies:
Ovaitt et al, Model and Validation of Single-Axis Tracking with Bifacial PV, JPV 2019. 10.1109/JPHOTOV.2019.2892872

Why long term data collection?

$$\frac{Energy\ bifacial}{Energy\ monofacial} - 1 \quad [\%]$$

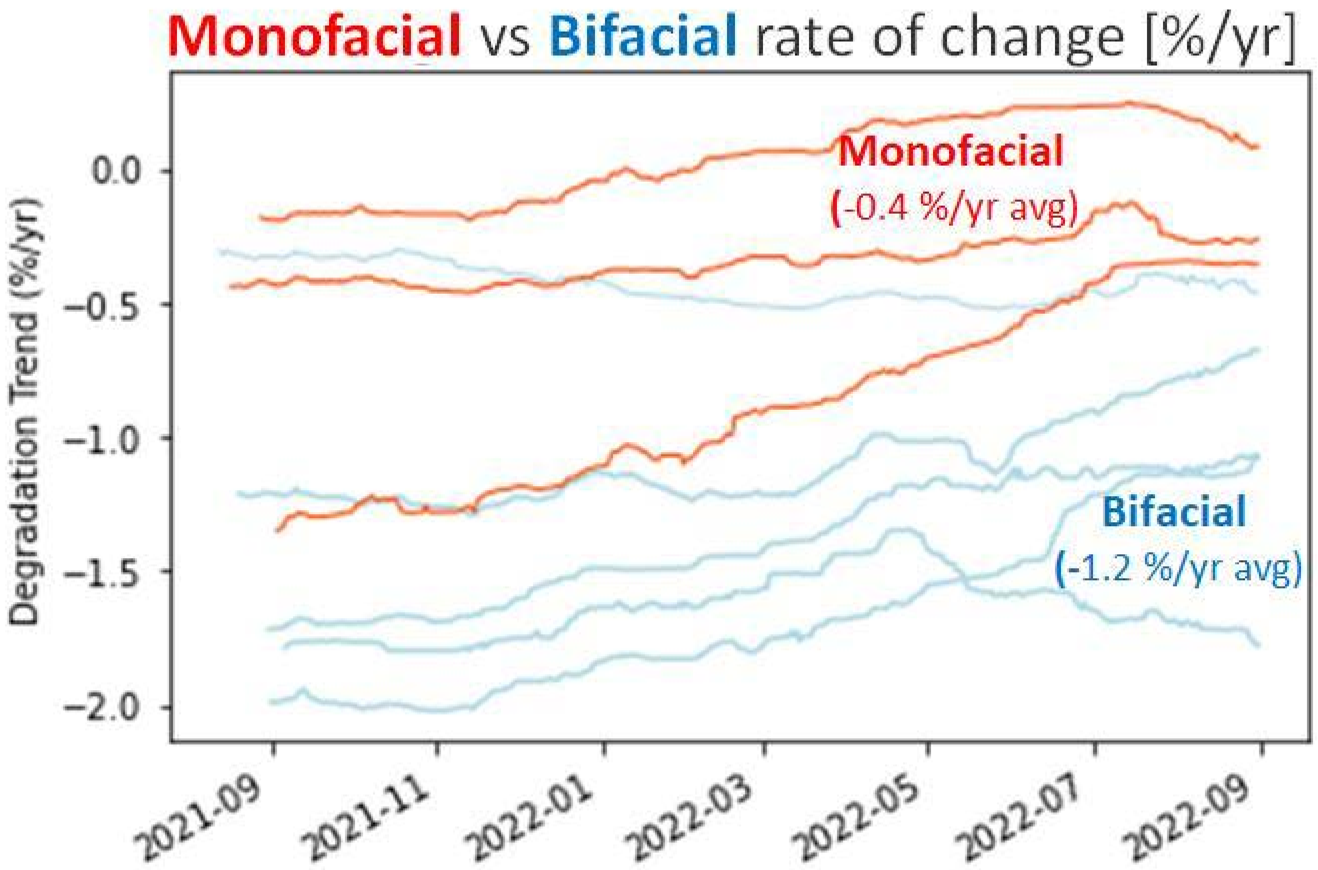
*Grouped by Month

PERC bifacial gain: 6.1%; SHJ gain: 7.6%



Why long term data collection?

- Initial Bifacial energy gain has a slight downward trend over 3 years.
- On average, **bifacial PERC and Si-HJT** are degrading faster than **monofacial counterpart**



RdTools Year-on year degradation trend, 12-month rolling average

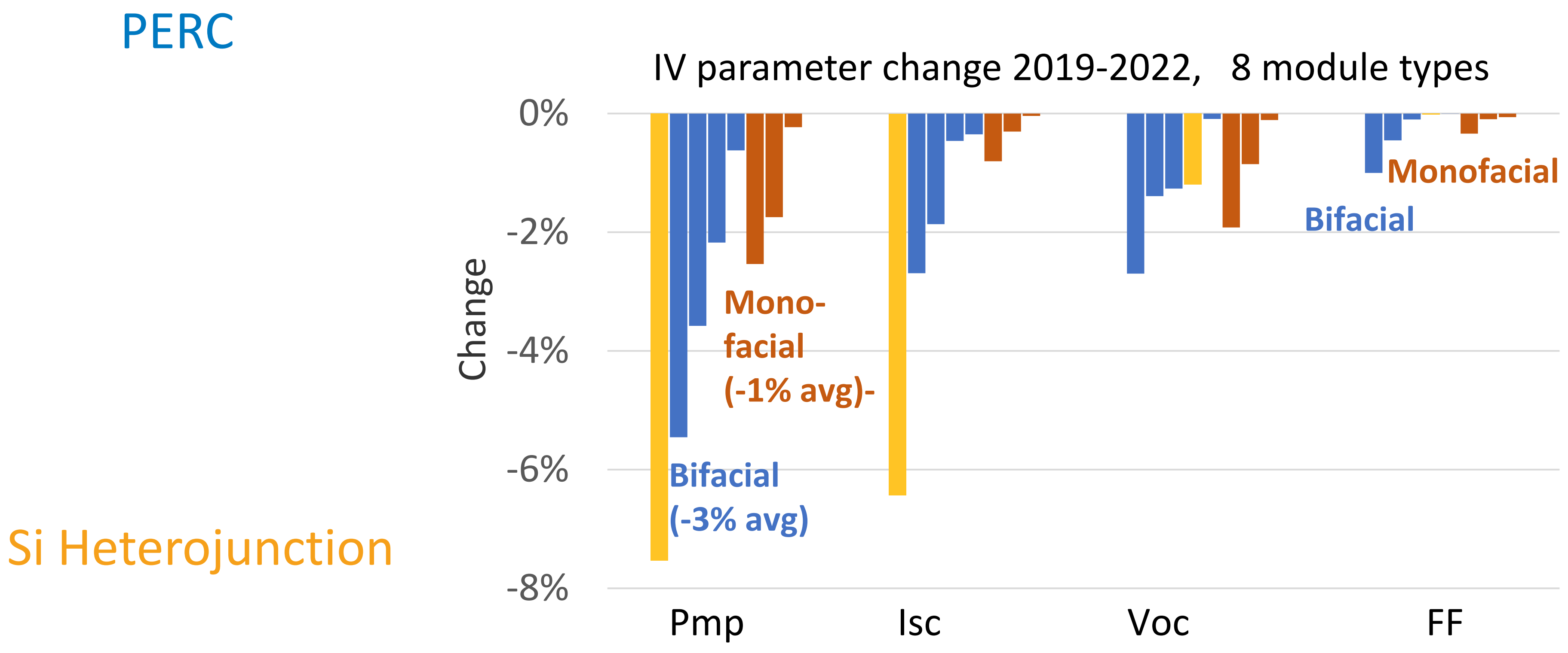
$$PR_n = daily\ perf.ratio$$

$$Rd_n = \frac{PR_{n+365} - PR_n}{\overline{PR}_{yr1}}$$

$$\frac{\sum_{365}^{1095} Rd_{n:(n+365)}}{365}$$

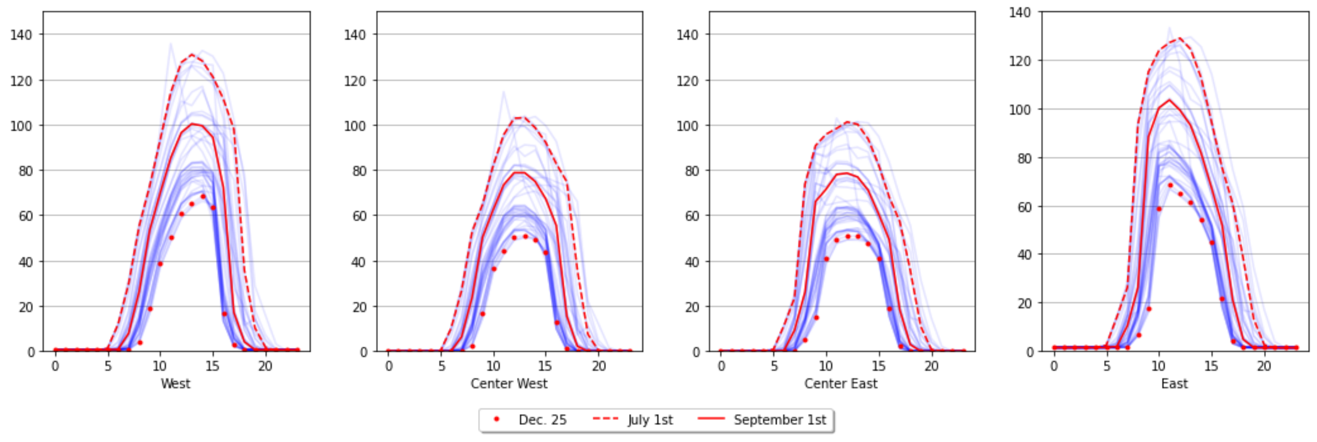
Why long term data collection?

- Indoor flash-test confirms performance loss; **Isc change** is the dominant difference
- Possible causes: Ga vs B doping, G/G vs G/backsheet, PID-p with high-conductivity encapsulant



Why so many irradiance sensors?

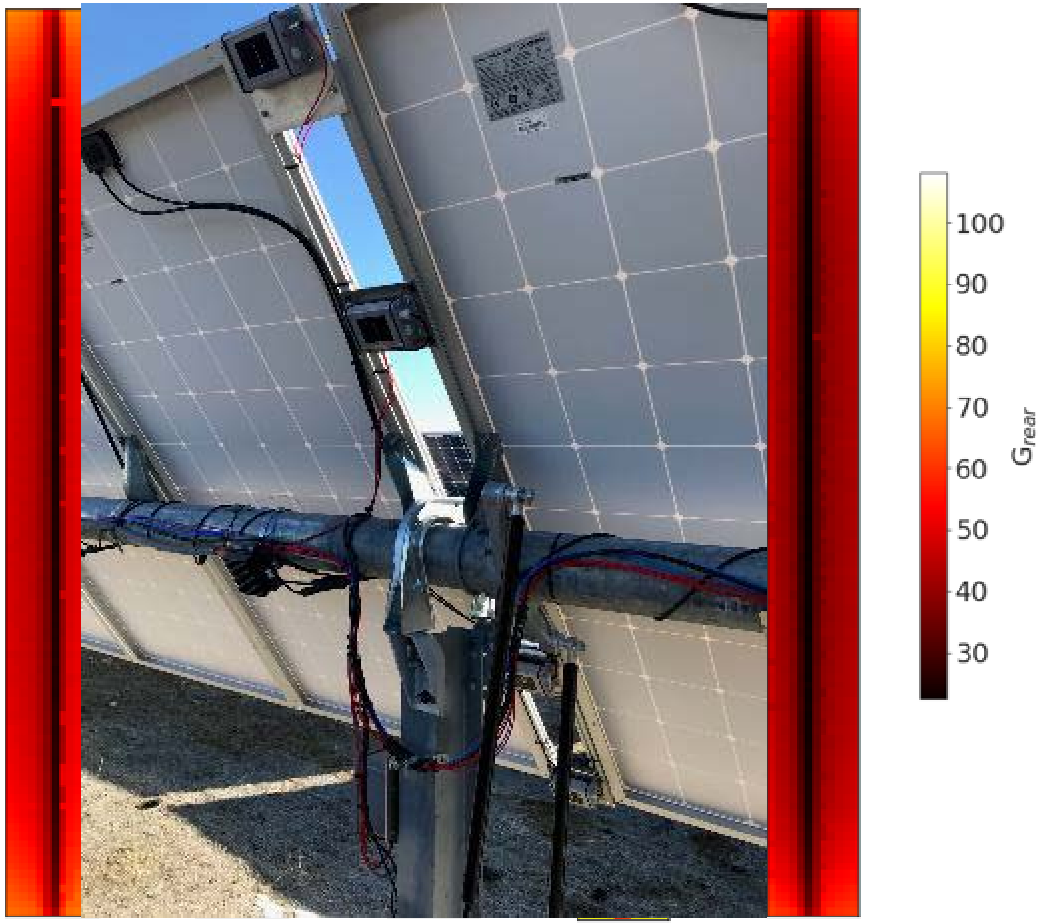
Clear-sky days October 2019-2021



% Difference from Reference Cell Mean

Ref. Cell (WEST)	7	-12	-8	13	Ref Cell (EAST)

June 1st



https://www.nrel.gov/docs/fy21osti/80281.pdf PVSC 21
https://www.nrel.gov/docs/fy20osti/73203.pdf PVSC 19

Why a hydra module?

Using a combination of sensors across the module can help reduce standard deviation of the measurements

SENSOR A

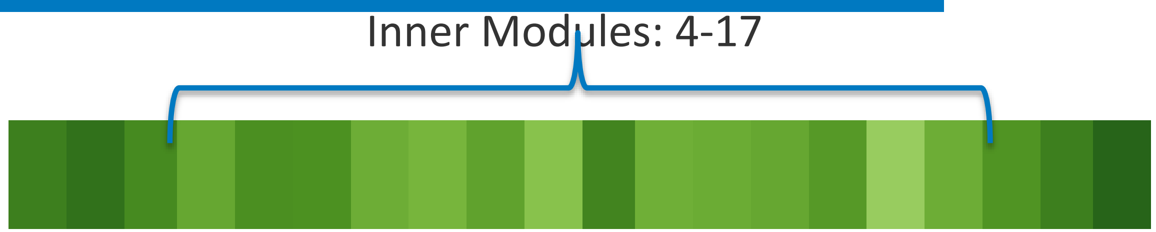
SENSOR B

Standard Deviation from Module average

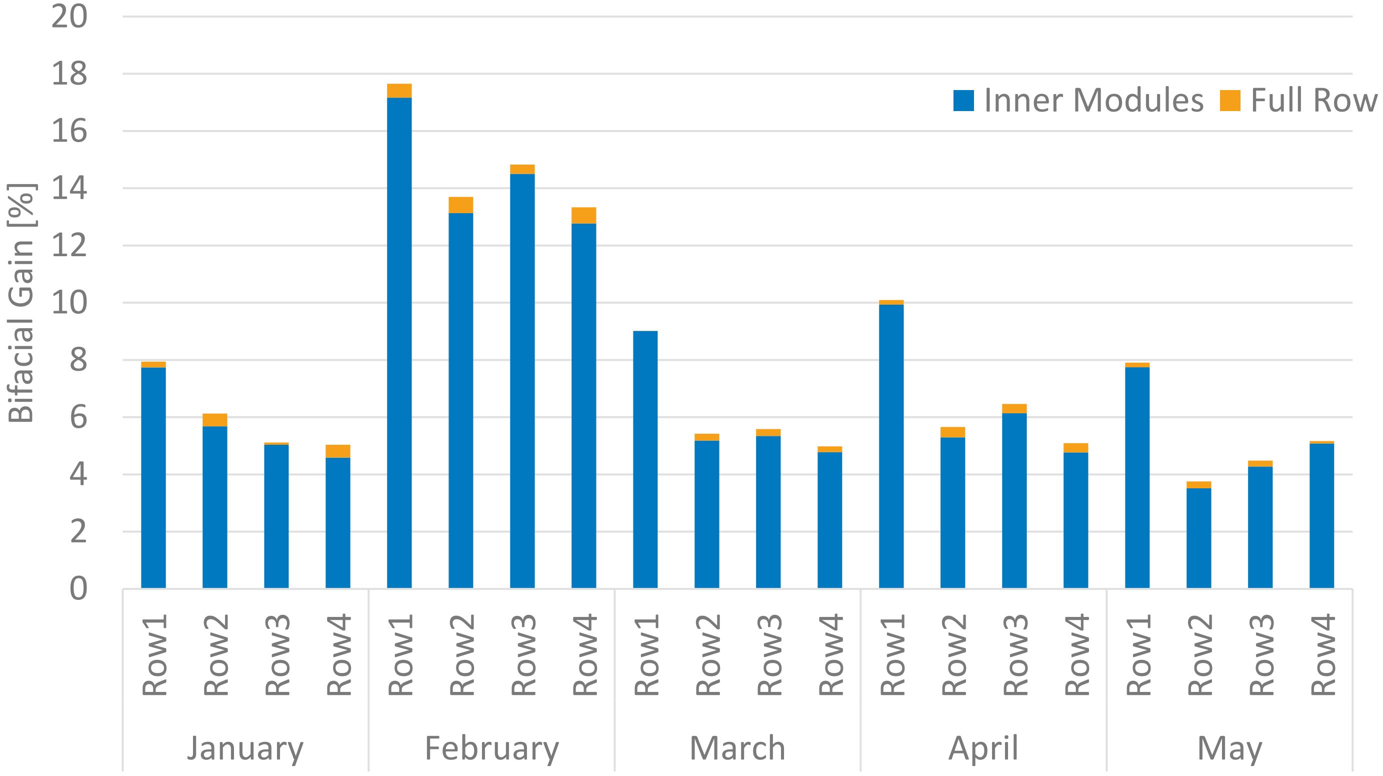
	1	2	3	4	5	6	7	8	9	10	11
2	0.10										
3	0.08	0.07									
4	0.07	0.07	0.06								
5	0.06	0.06	0.06	0.07							
6	0.05	0.05	0.05	0.06	0.08						
7	0.04	0.03	0.04	0.05	0.07	0.08					
8	0.03	0.02	0.02	0.04	0.06	0.07	0.08				
9	0.04	0.03	0.01	0.02	0.04	0.05	0.06	0.06			
10	0.05	0.04	0.02	0.01	0.03	0.04	0.05	0.05	0.06		
11	0.07	0.05	0.03	0.02	0.02	0.04	0.05	0.06	0.06	0.07	
12	0.08	0.07	0.05	0.04	0.03	0.04	0.05	0.06	0.08	0.09	0.10

More on how and why measure rear-irradiance:
Gostein, Ovaitt et al PVSC 2021 https://ieeexplore.ieee.org/document/9518601

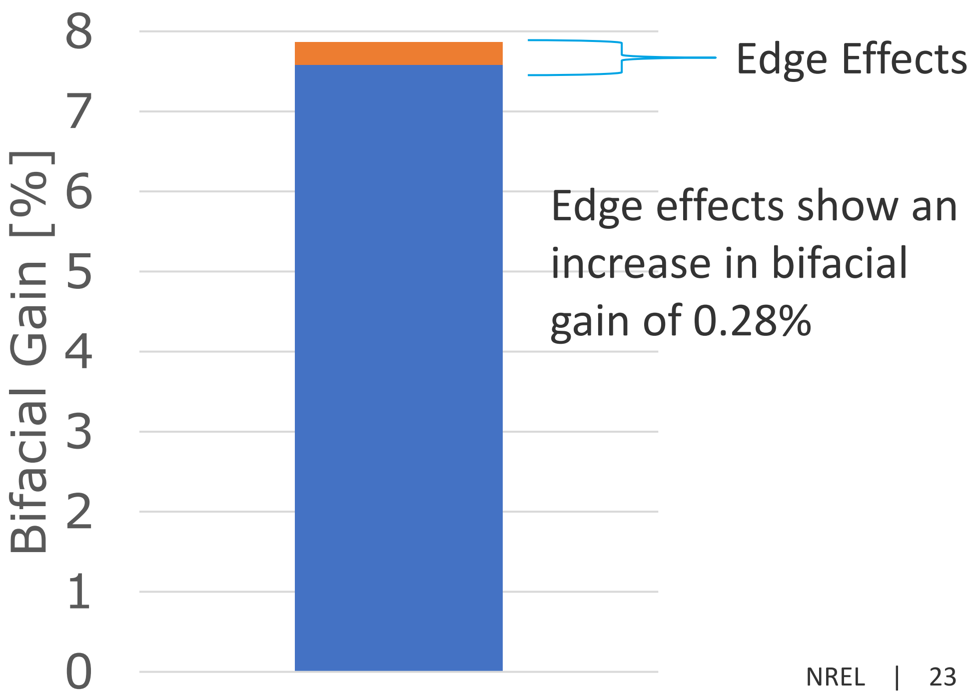
Why module level optimizers?



By Technology, Monthly



Cumulative effect



Optimized Albedo Placement Experiment
HSAT

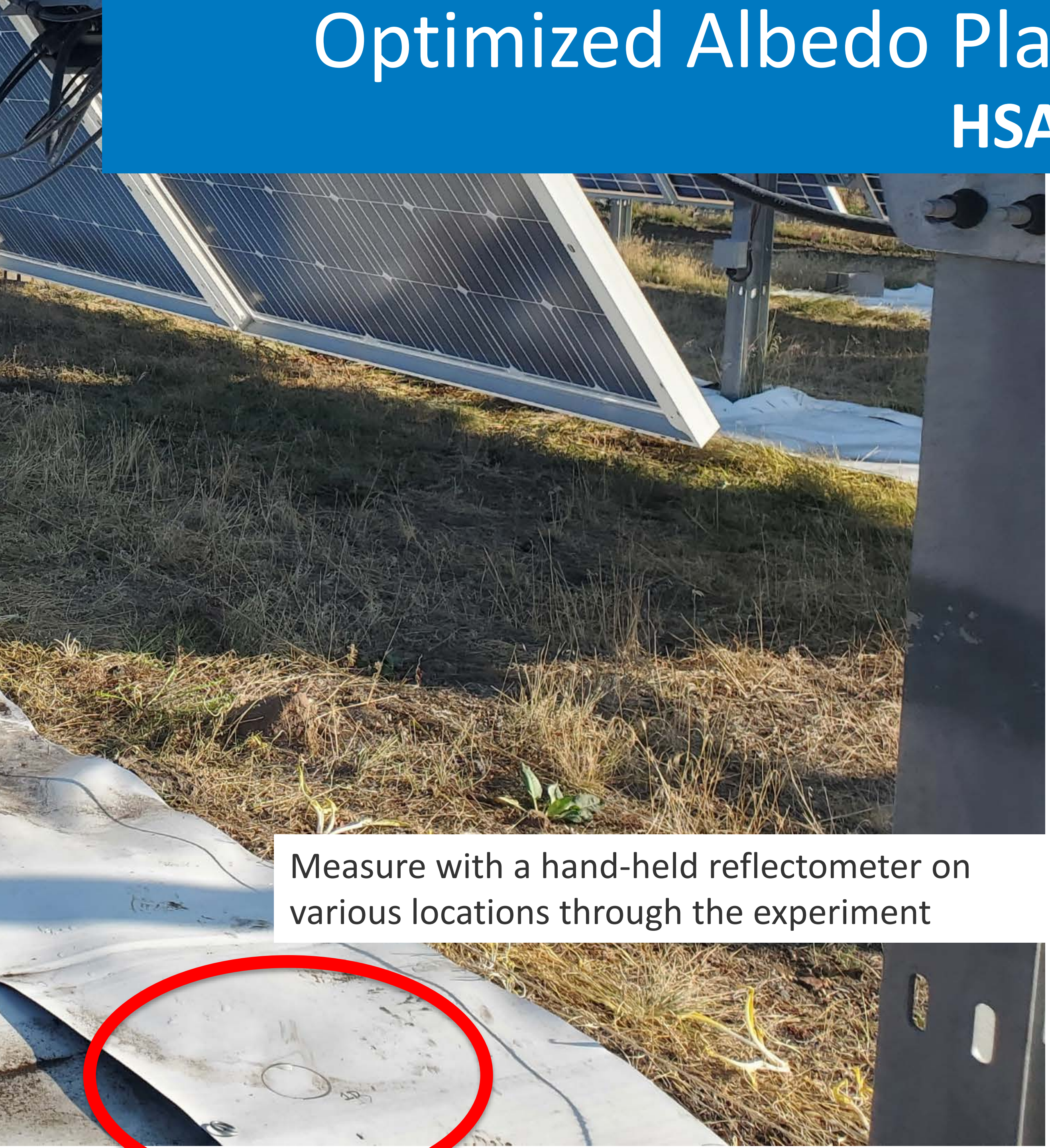
+5% Gain in the Bifacial Performance

Optimized Albedo Placement Experiment

HSAT

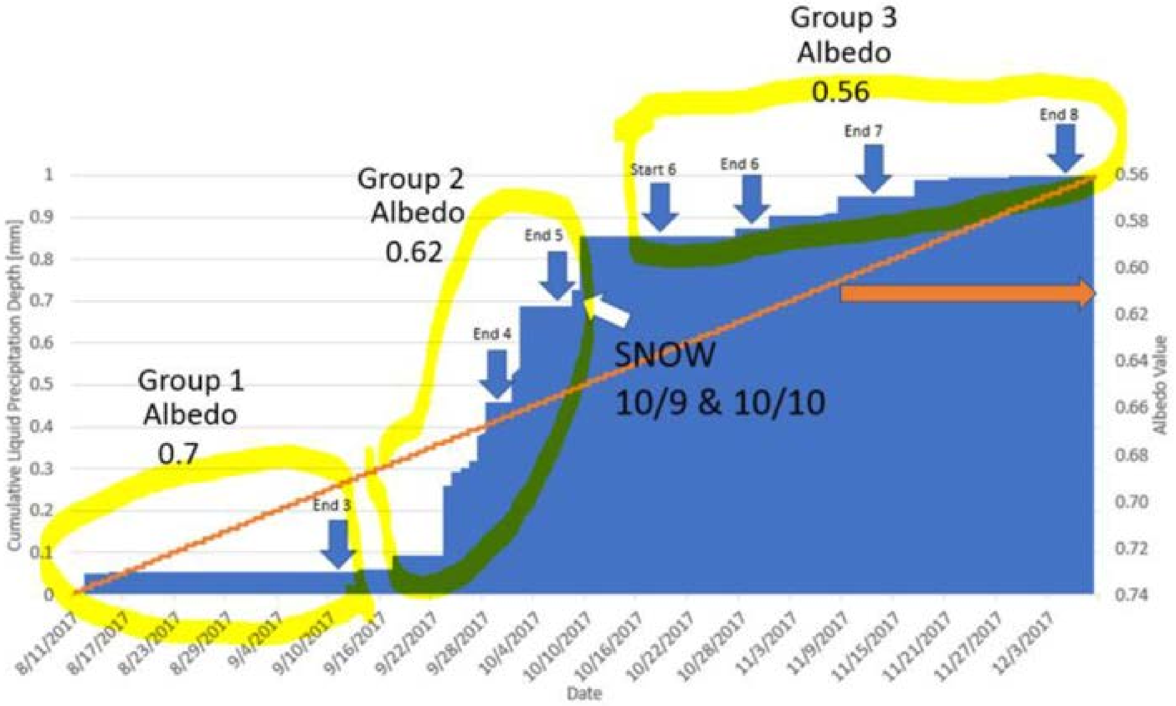
Optimized Albedo Placement Experiment

HSAT



Measure with a hand-held reflectometer on various locations through the experiment

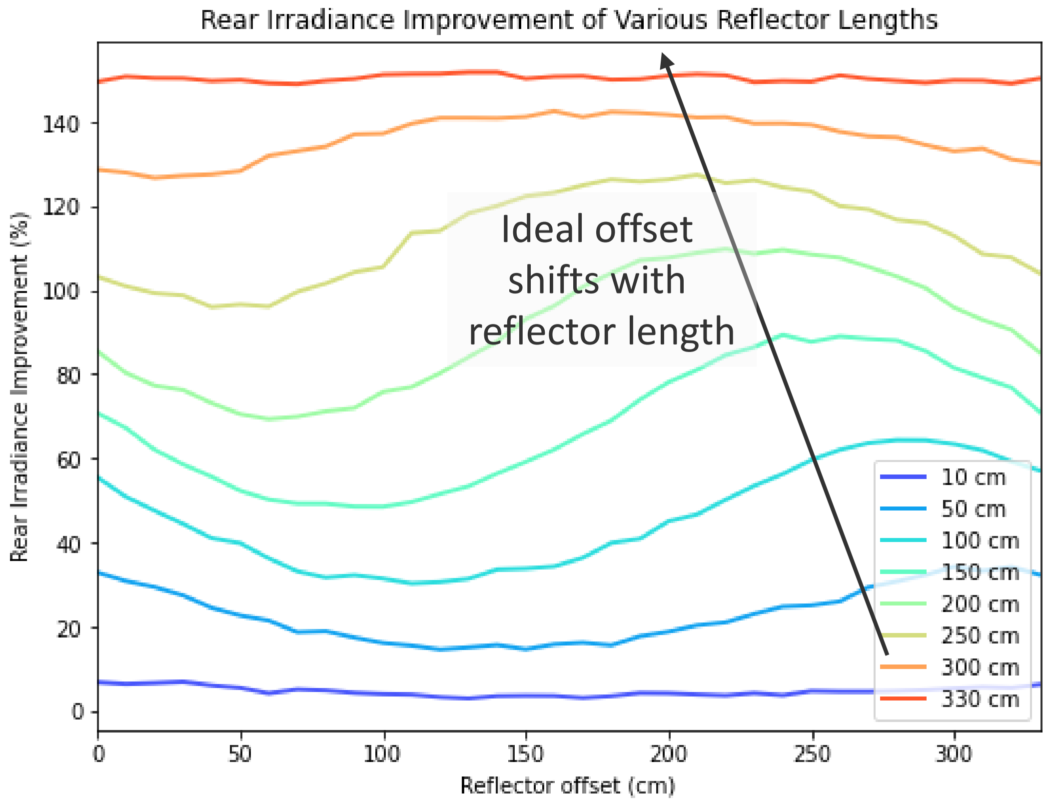
Previous 'high reflectivity' rooftop material reduced from 0.7 to 0.56 on 4 months*

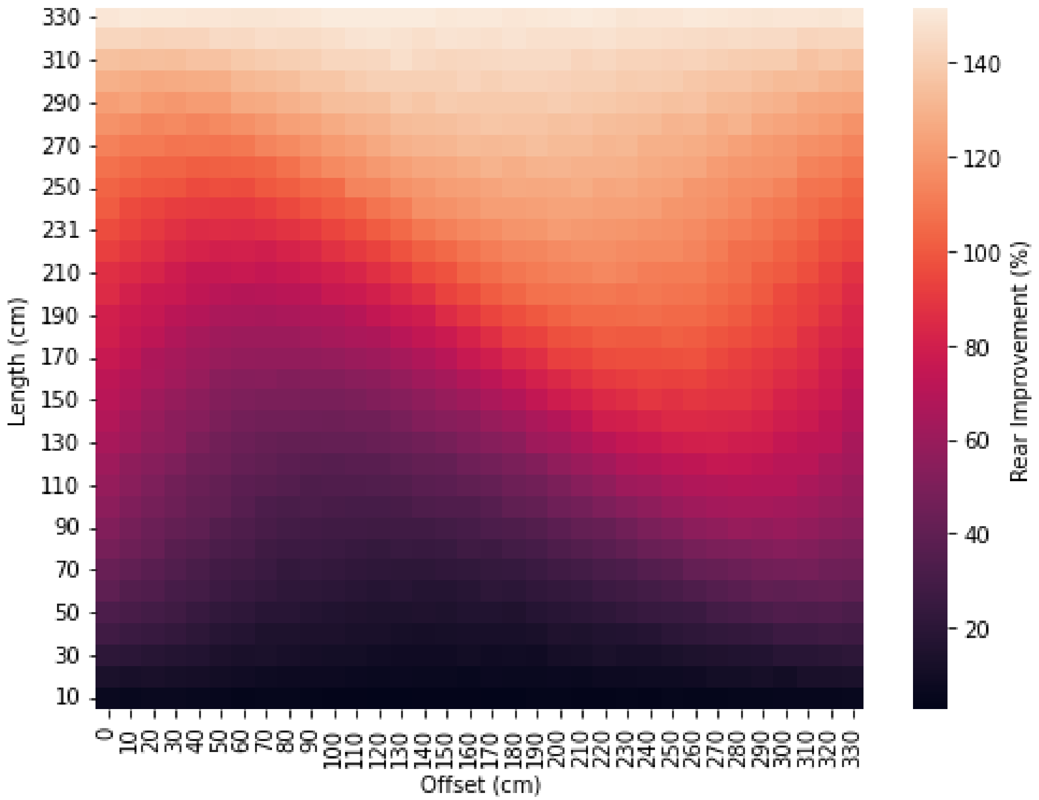


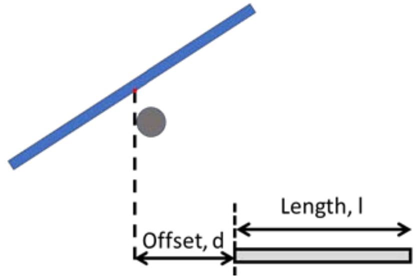
https://ieeexplore.ieee.org/abstract/document/8534404

Optimized Albedo Placement

Fixed Tilt







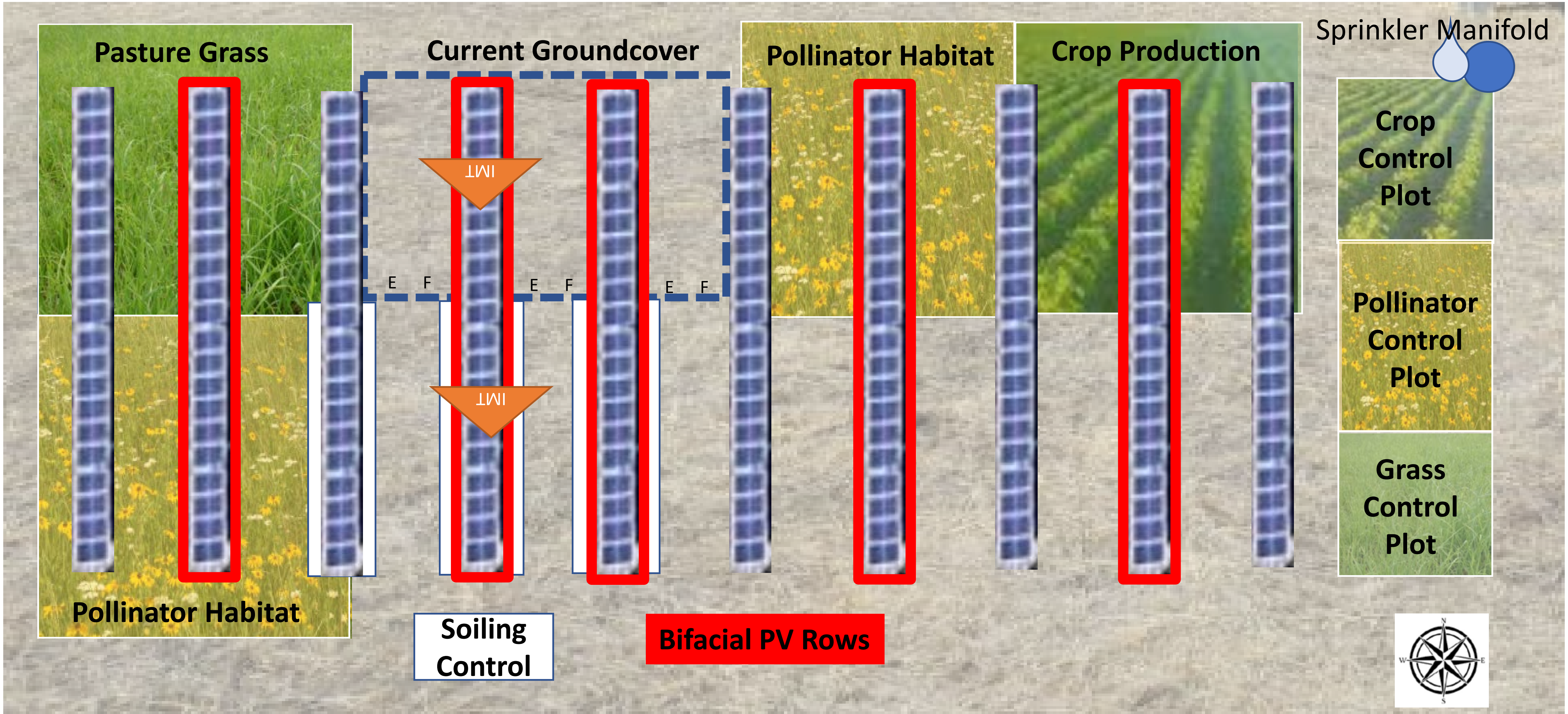
Avg. Rear Irr. (w/reflector)

$$\% \, Rear \; Irr. \; Imp. = \frac{G_{rear} - G_{ref}}{G_{ref}}$$

Avg. Rear Irr. (w/o reflector)

1 summer of AgriPV

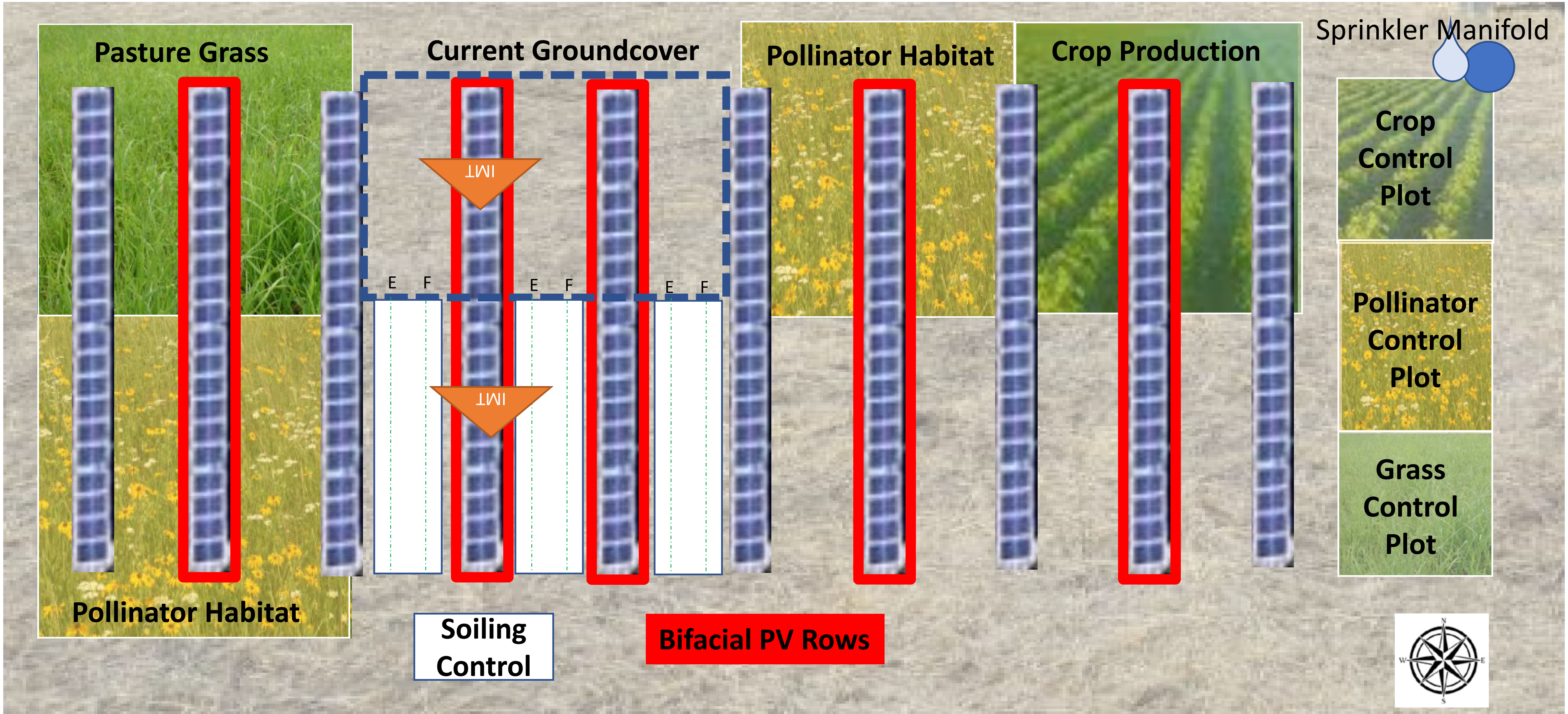
SETUP 3: 25% centered on torque tube



Optimized Albedo Placement Experiment

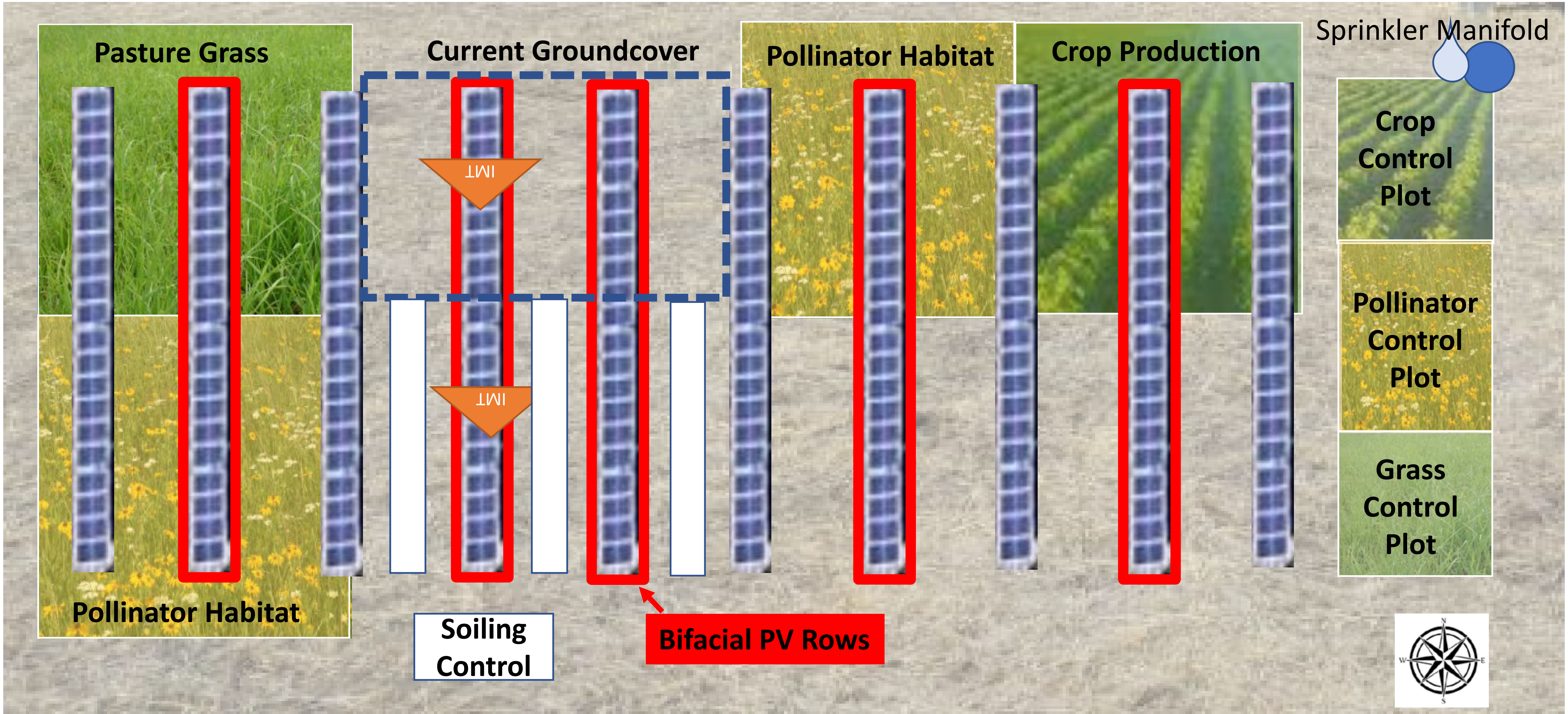
HSAT

SETUP 4: STAKE NEW MATERIAL, 50% coverage between rows

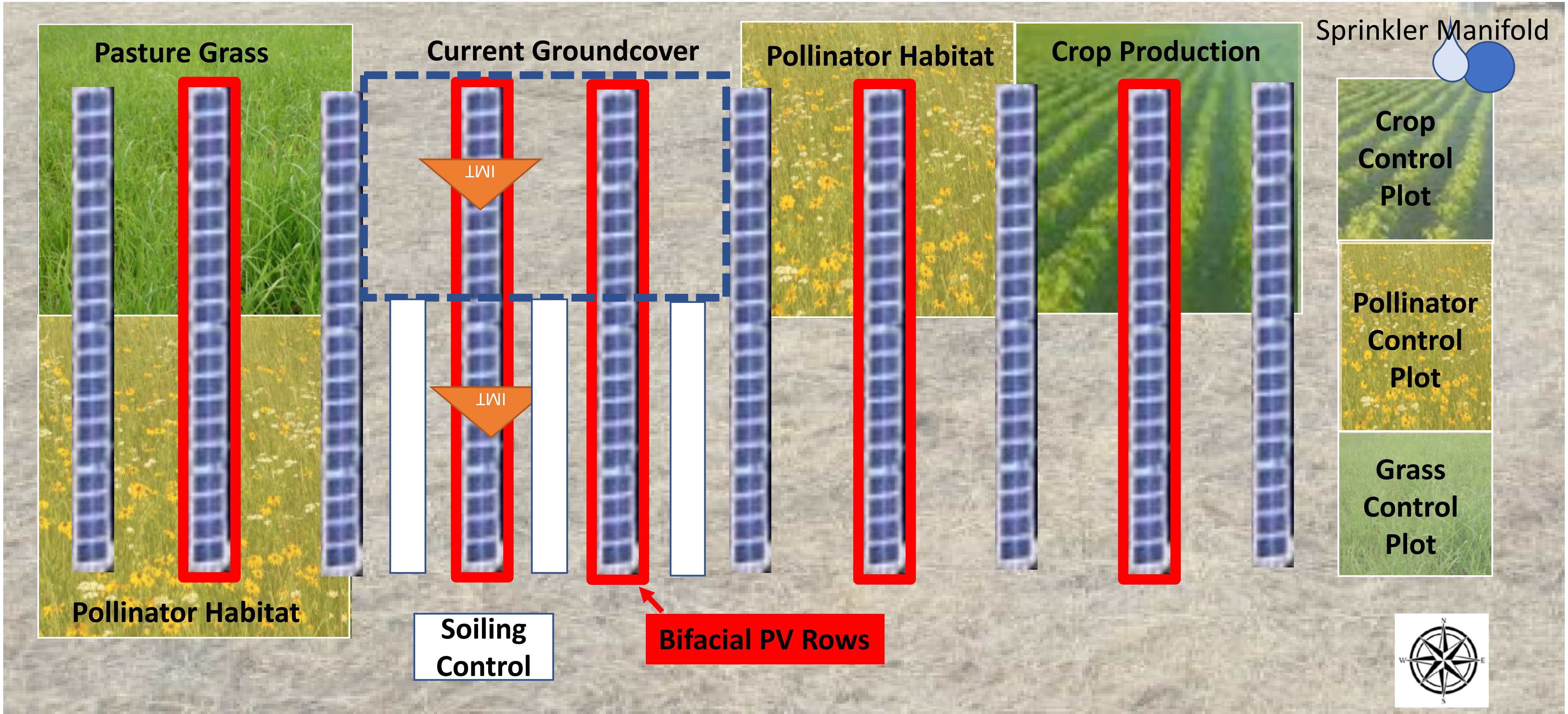


Optimized Albedo Placement Experiment
HSAT

SETUP 5: CUT Material on Edges E and F, 25% coverage between rows



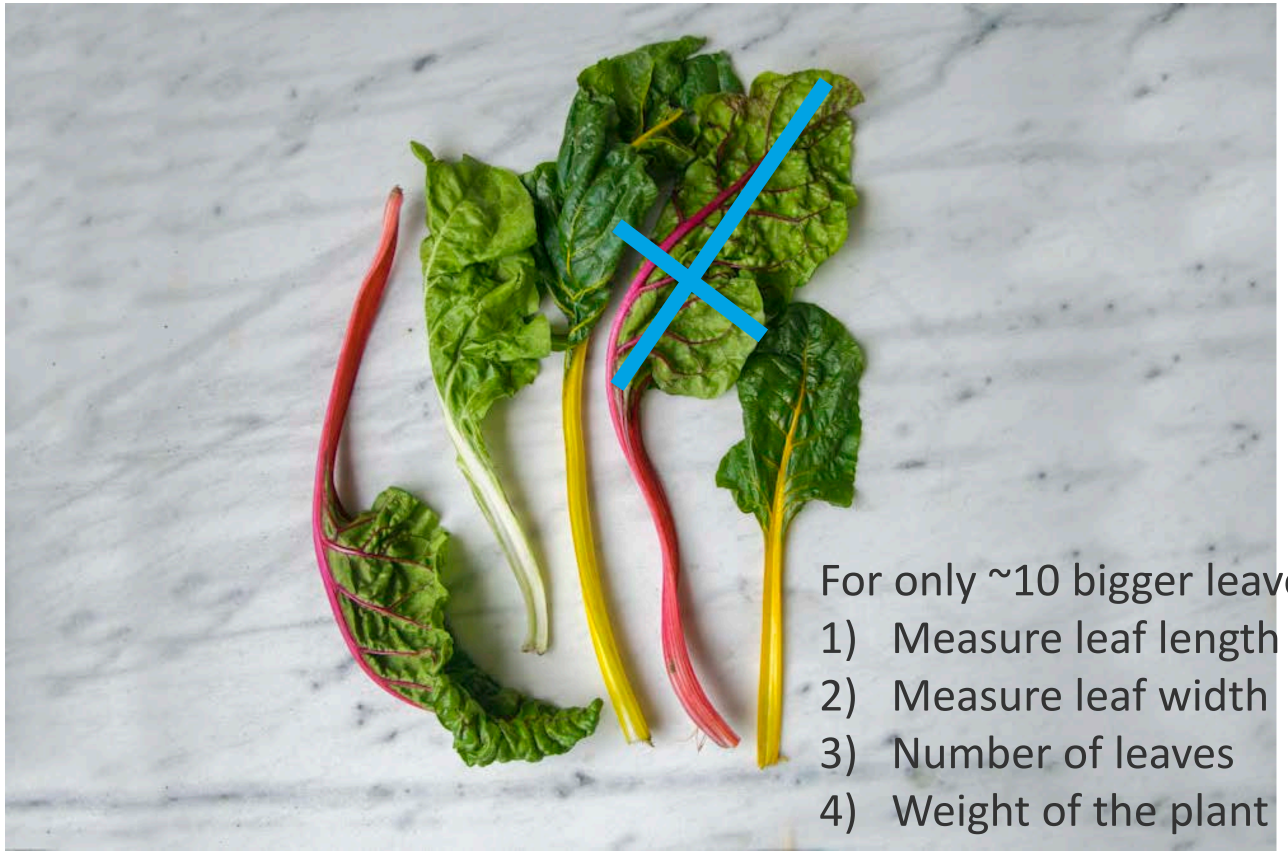
AgriPV: Crop, pasture, pollinator habitat

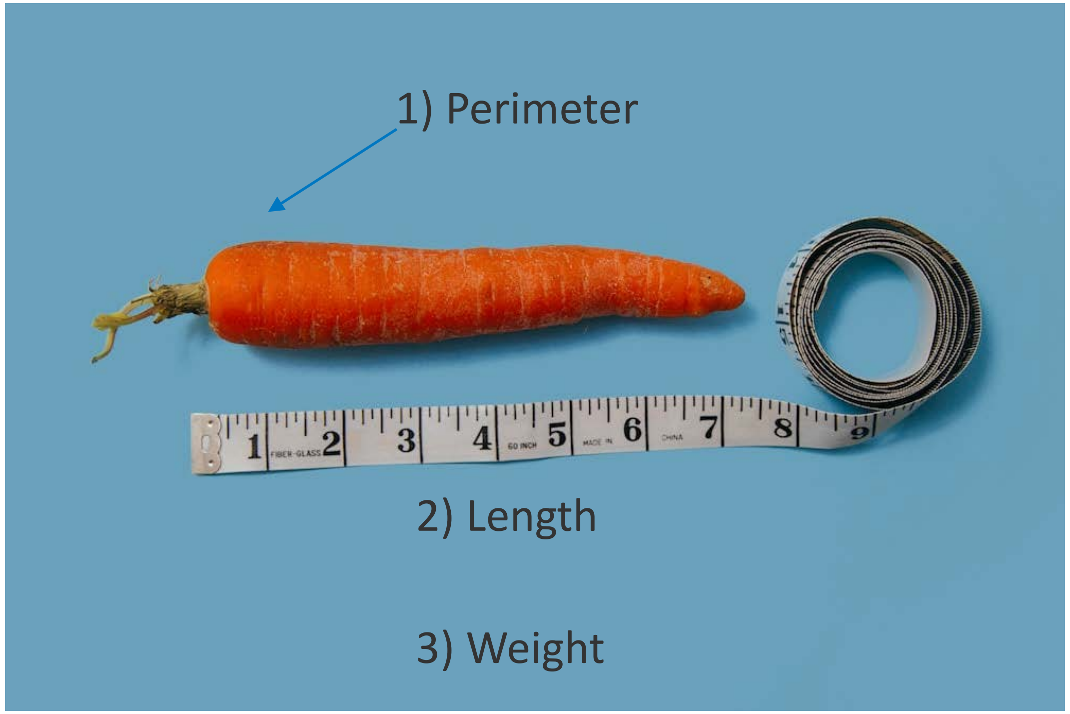


1 Summer of AgriPV

Planted on June 6, Harvests until October 21

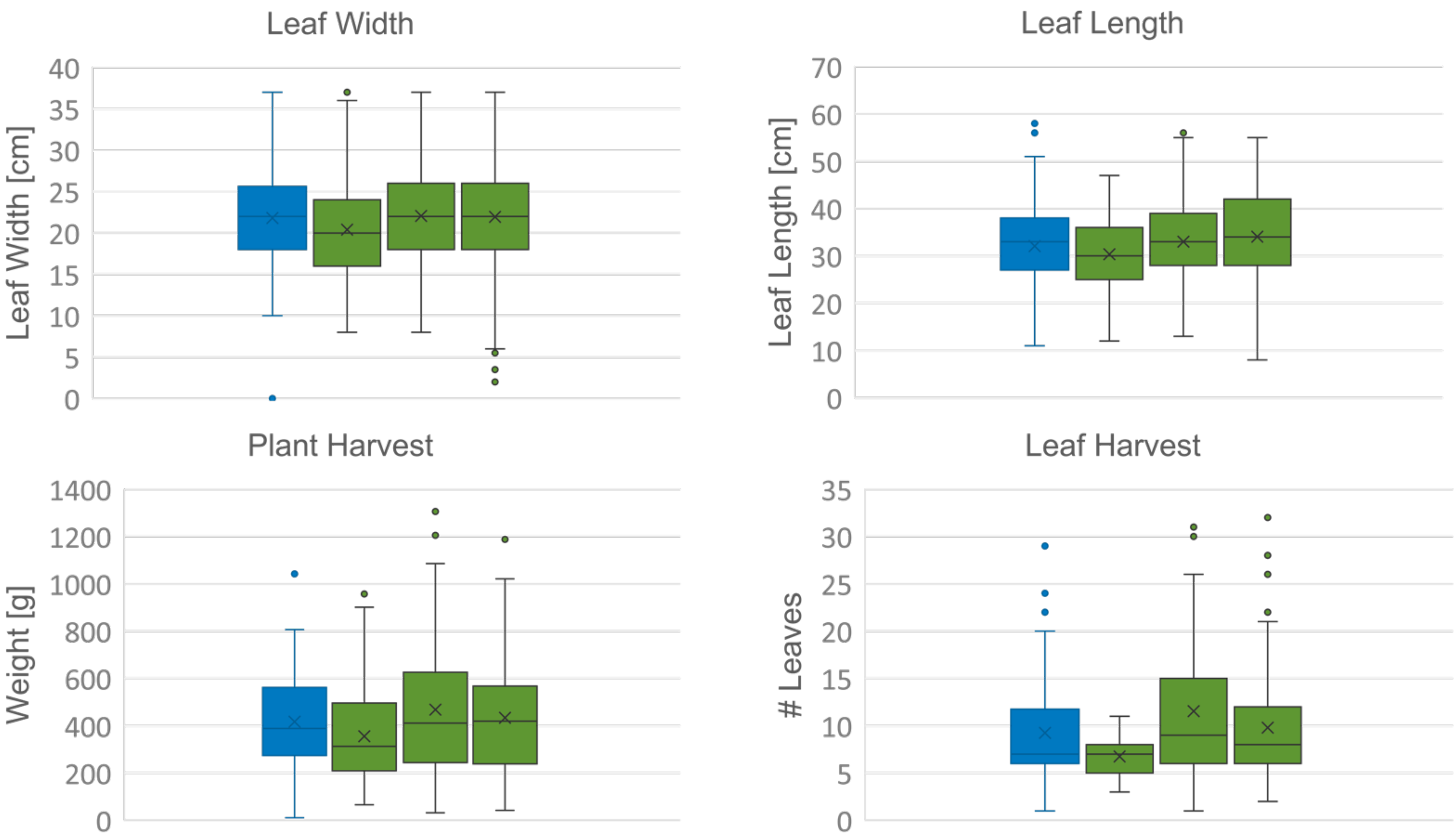
Season 1 Bifacial Farm Results



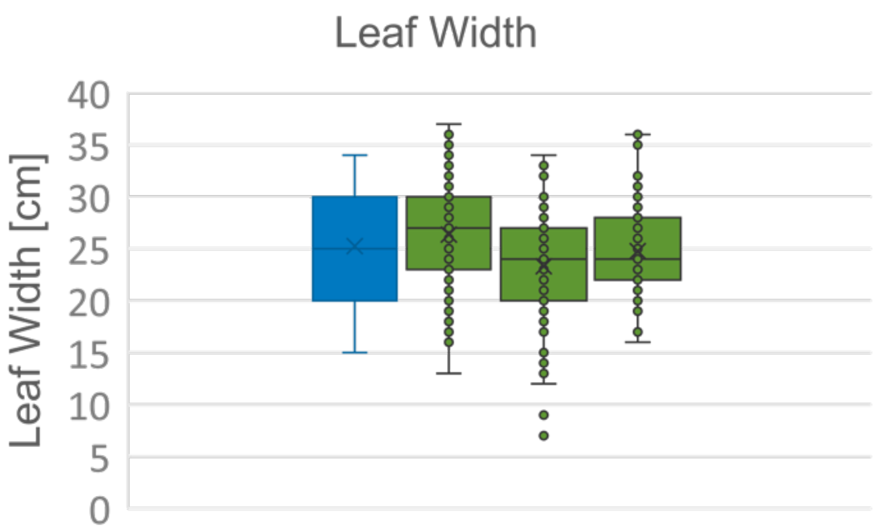


±0% Gain in the Bifacial Performance

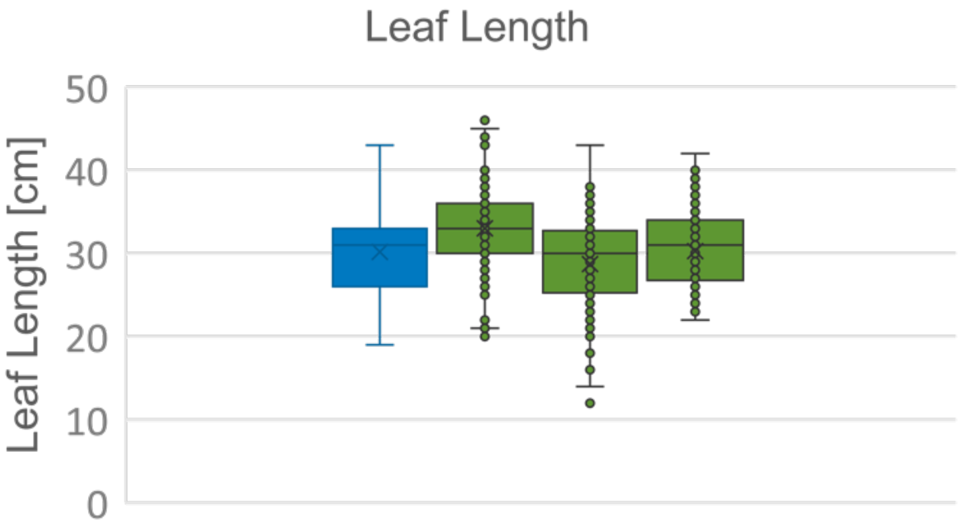
Chard


Leaf Width
Leaf Width [cm]
0
5
10
15
20
25
30
35
40
Leaf Length
Leaf Length [cm]
0
10
20
30
40
50
60
70
Plant Harvest
Weight [g]
0
200
400
600
800
1000
1200
1400
Leaf Harvest
Leaves
0
5
10
15
20
25
30
35

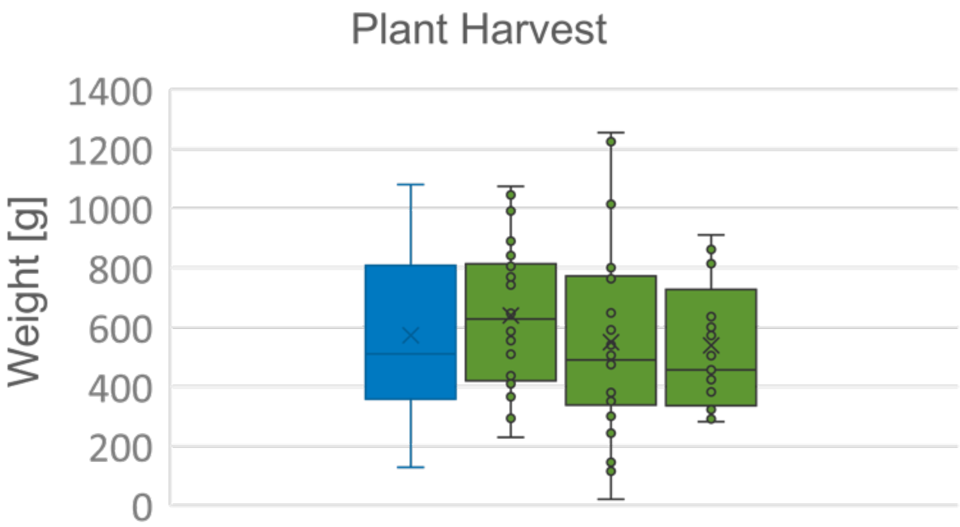
Kale



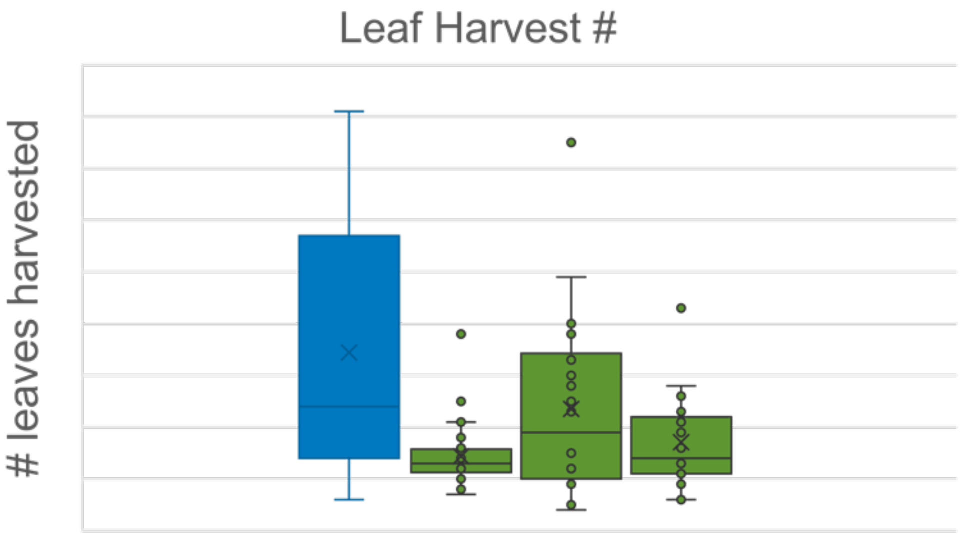
Leaf Width
Leaf Width [cm]
40
35
30
25
20
15
10
5
0



Leaf Length
Leaf Length [cm]
50
40
30
20
10
0

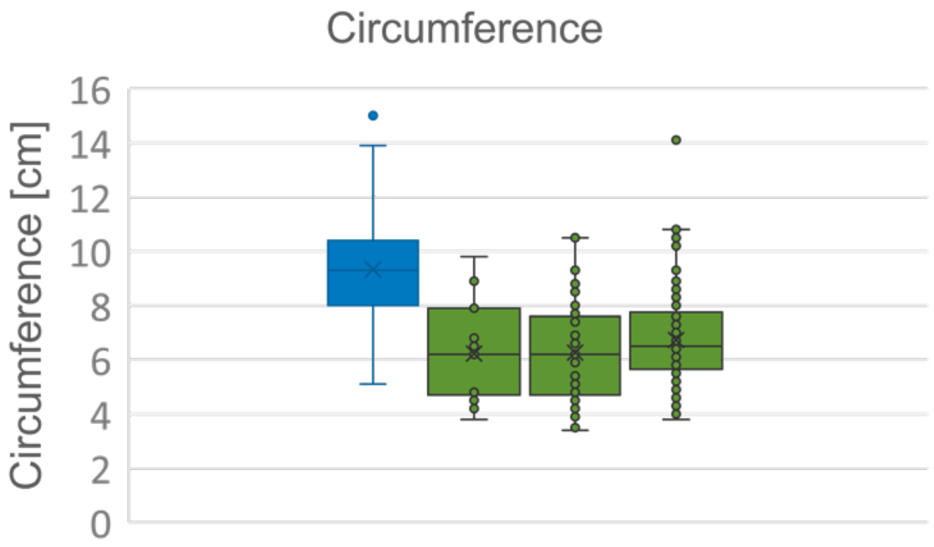


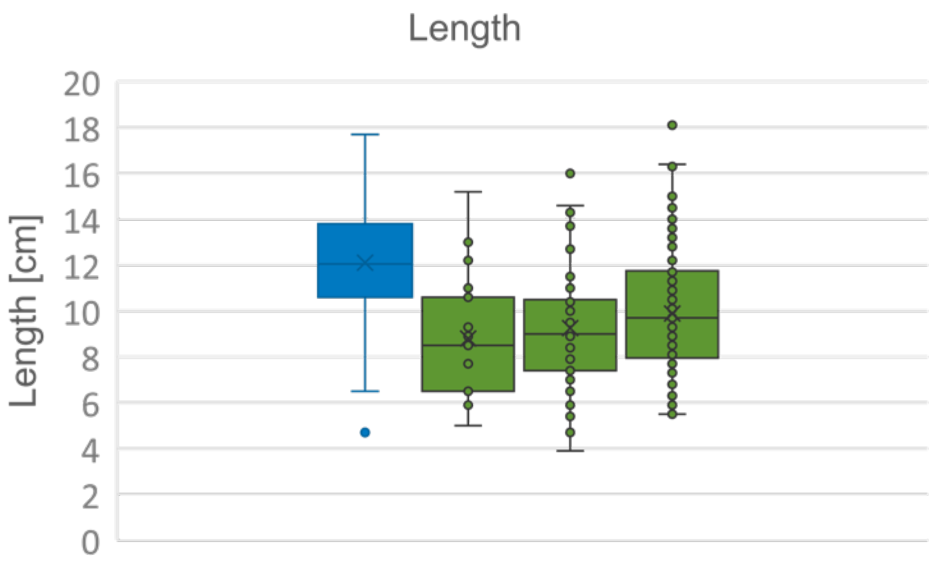
Plant Harvest
Weight [g]
1400
1200
1000
800
600
400
200
0

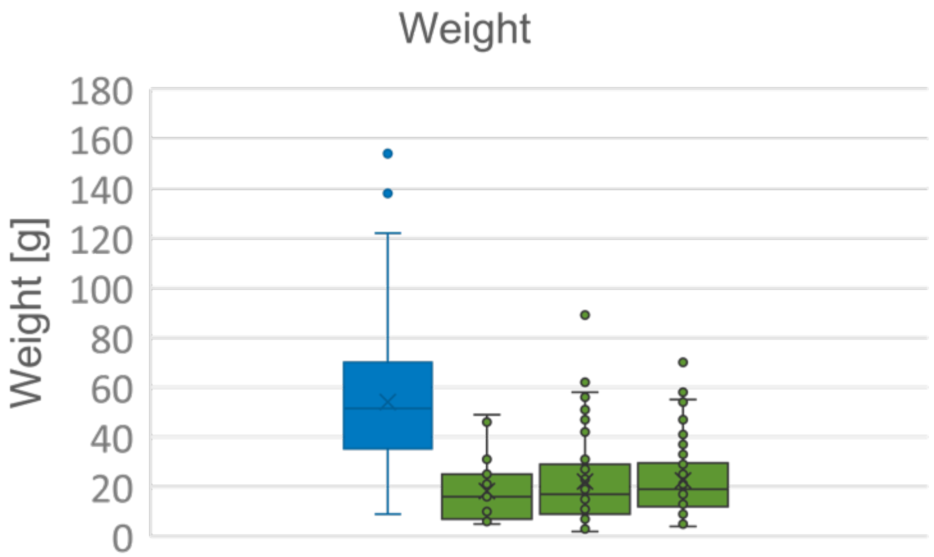


Leaf Harvest #
leaves harvested

Carrots





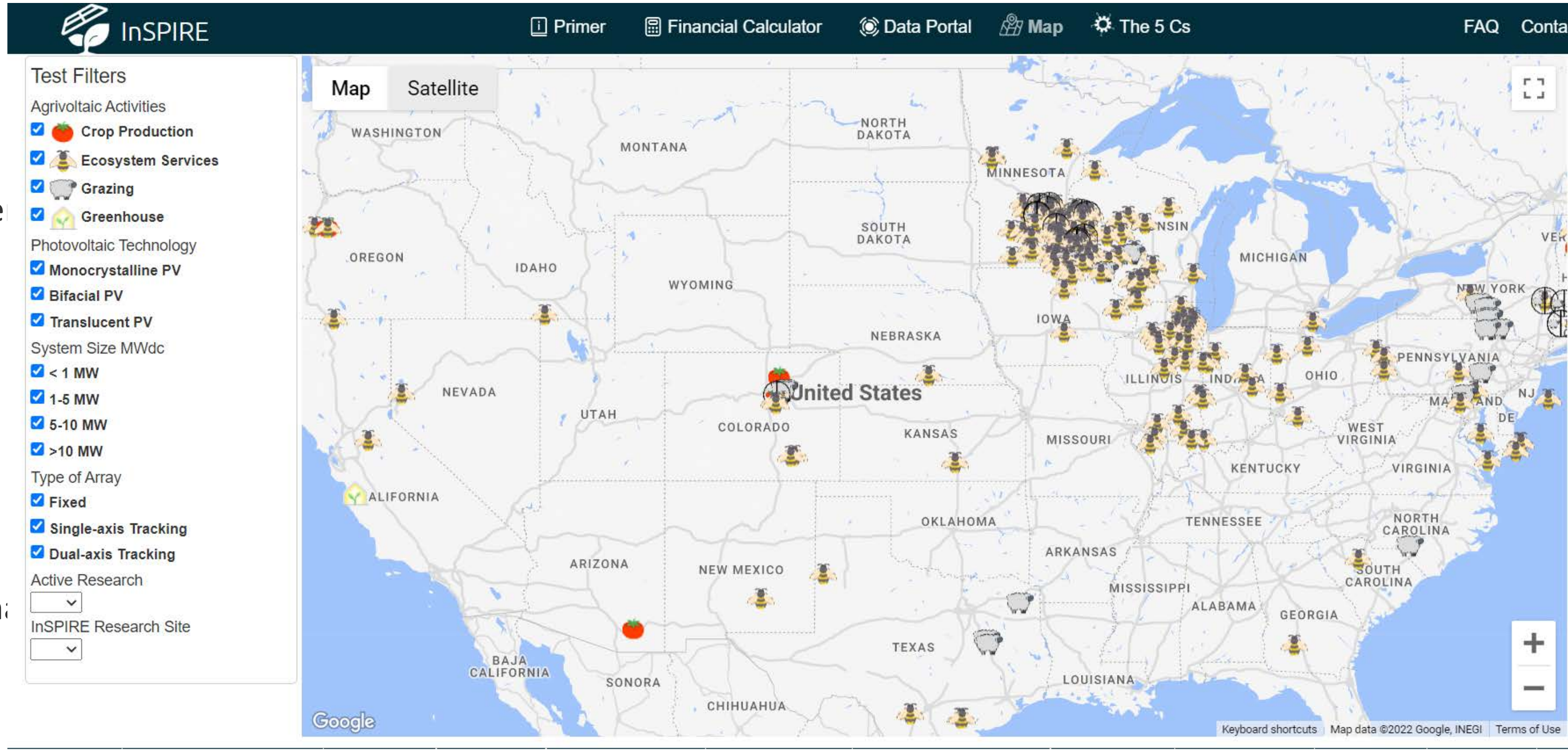


- Poor germination in the beginning of the year (partially due to deer walking on it), and the lower light was not great for them.
- Not enough observations to write it off yet – looking forward to next season for more data.

AgriPV Research

Harvesting team notes

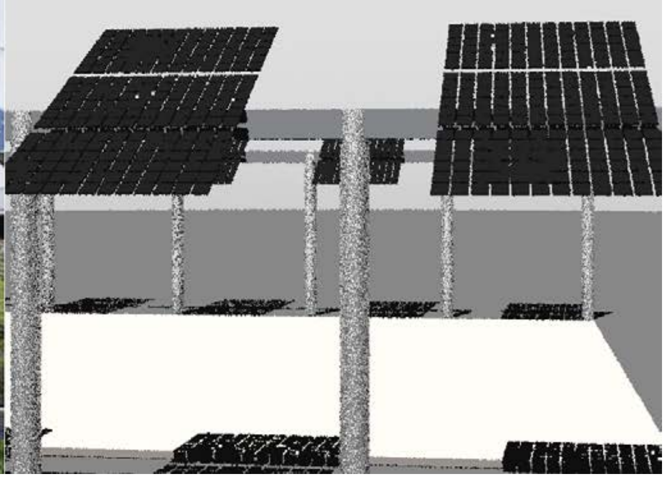
'4 stripey jump insects'
'3 broken leaves'
'1 fly'
'2 gnats'
'jumpy bugs'
'2 leaves snapped'
'1 leaf very consumed. 1 slightly consumed. 6 mode
'2 leaves with insect damage'
'5 leaves with bites taken'
'had preying mantis babies'
'mostly burn and unharvestable'
'few small bites'
'bottom leaves browning'
'was on the brink of death, growing again'
'was on brink of death but has made a recovery'
'some kind of sticky substance on the plant, it's unh
'deer ate all the leaves'
'plant pulled/eaten'
'pulled due to aphids'
'Most plants were pulled due to aphid infestation.
If no harvest weight is given, no leaves were marketable'
'leaning heavily'
'(is actually the second plant, 1st plant is gone)'

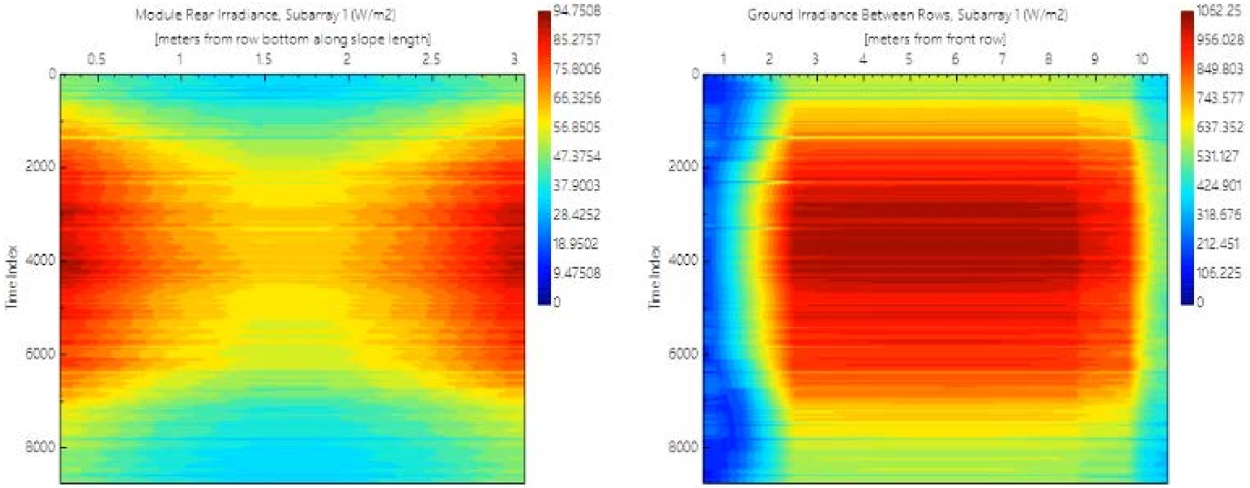


More on the InSPIRE AgriPV Project (4 GW of projects, 56 sites research oriented):
https://openei.org/wiki/InSPIRE/Agrivoltaics_Map

Modeling Tools Updates

- SAM Roadmap for Bifacial
  - GHI under the modules data for AgriPV evaluation (already on *bifacialVF*)
  - Different ground albedos
  - Shading, and Electrical Mismatch Bifacial loss calculated internally*
- bifacial_radiance
  - Routines from start-to-end weather to Performance with PVLib
  - Edge effects, electrical mismatch detailed calculation, shading routines
  - Complex model geometry: frames, omegas, glass
  - AWS support & tutorials





*Deline et al, 2020 https://doi.org/10.1002/pip.3259

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