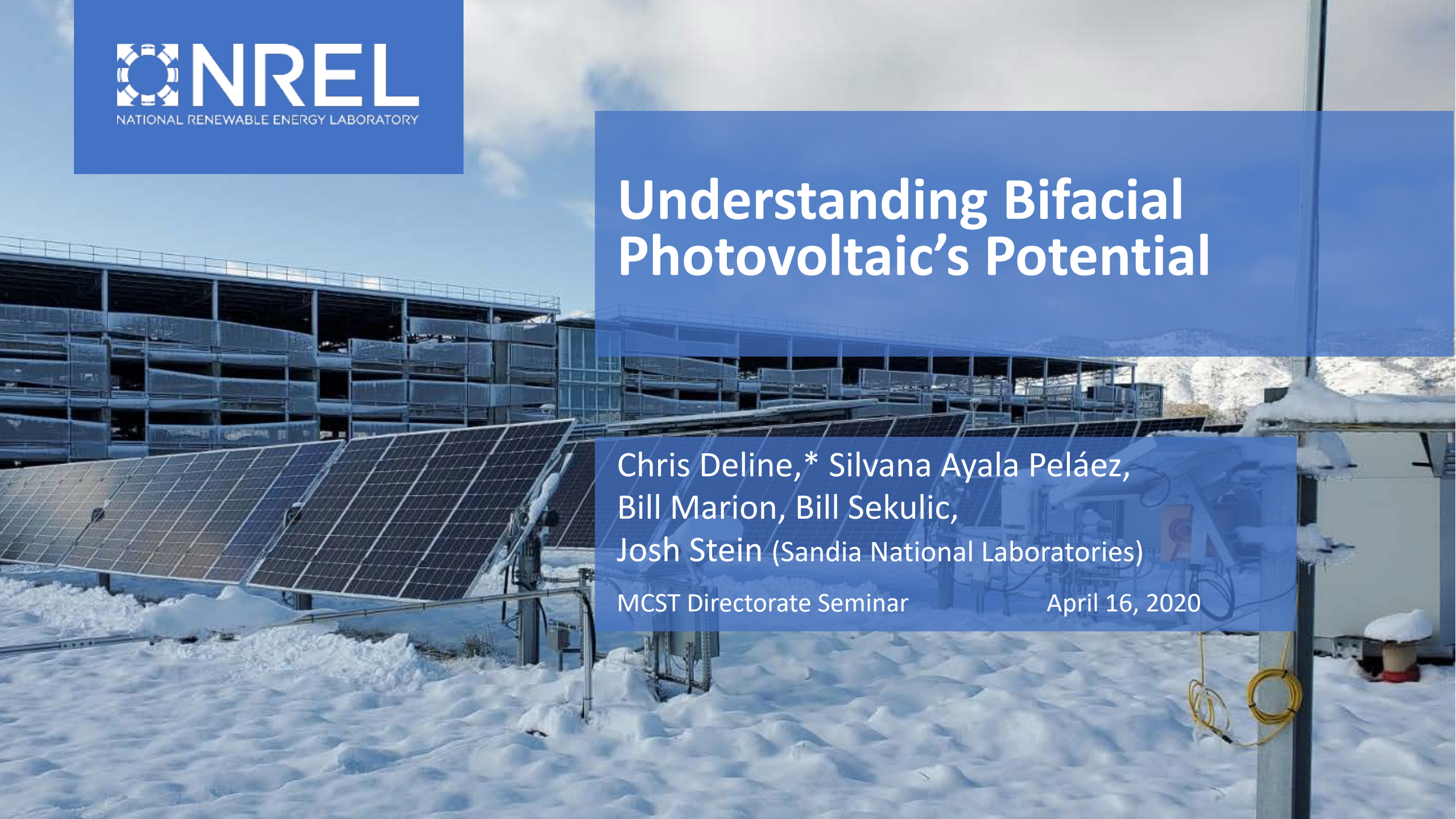


NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Understanding Bifacial Photovoltaic's Potential

Chris Deline,* Silvana Ayala Peláez,
Bill Marion, Bill Sekulic,
Josh Stein (Sandia National Laboratories)

MCST Directorate Seminar April 16, 2020

Bifacial PV in the news

Bifacial beats Trump's tariffs

Federal trade authorities have ruled that bifacial solar modules are no longer sub
the Section 201 ruling, which currently apply a 25% tariff to most solar modules i
to the United States.

JUNE 12, 2019 JOHN WEAVER

BUSINESS | COST AND PRICES | MARKETS | MODULES & UPSTREAM MANUFACTURING | POLICY | UNITED STATES

Georgia will be home to largest solar PV project in th
to use bifacial modules and tracking

February 25, 2019

By Renewable Energy World Editors

Canadian Solar Secures Its Largest Order as Bifacial Modules Gain Traction

EDF Renewable Energy will buy 1.8 gigawatts of modules from Canadian Solar as the Investment Tax Credit phases down, in a sign that developers are growing more comfortable with two-sided solar technology.

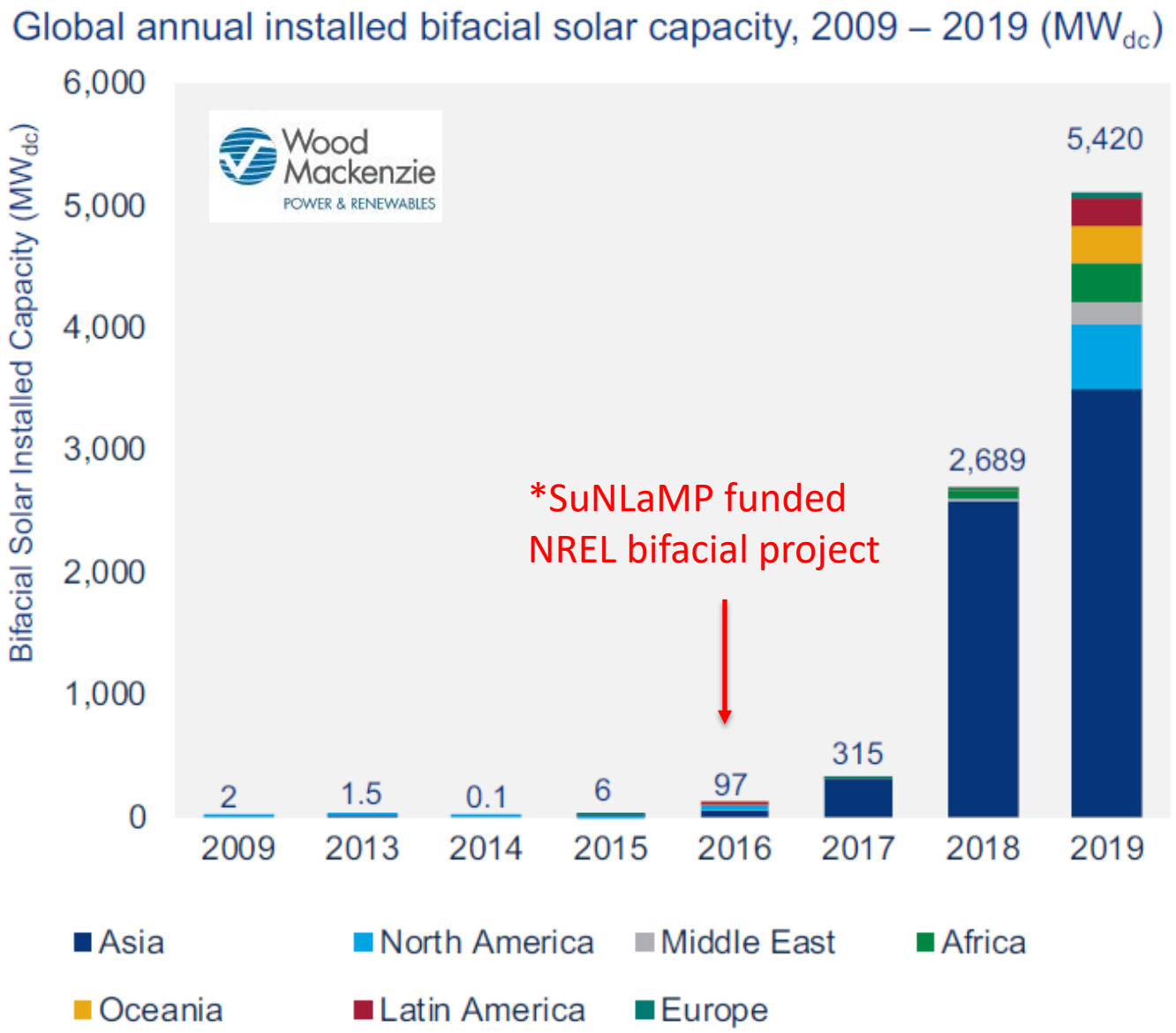
KARL-ERIK STROMSTA | MAY 29, 2019

2

Scatec Solar's first bifacial project goes live in Egypt

By José Rojo Martín | Apr 12, 2019 10:44 AM BST | 0 | Share

Status of Bifacial Installations 2019



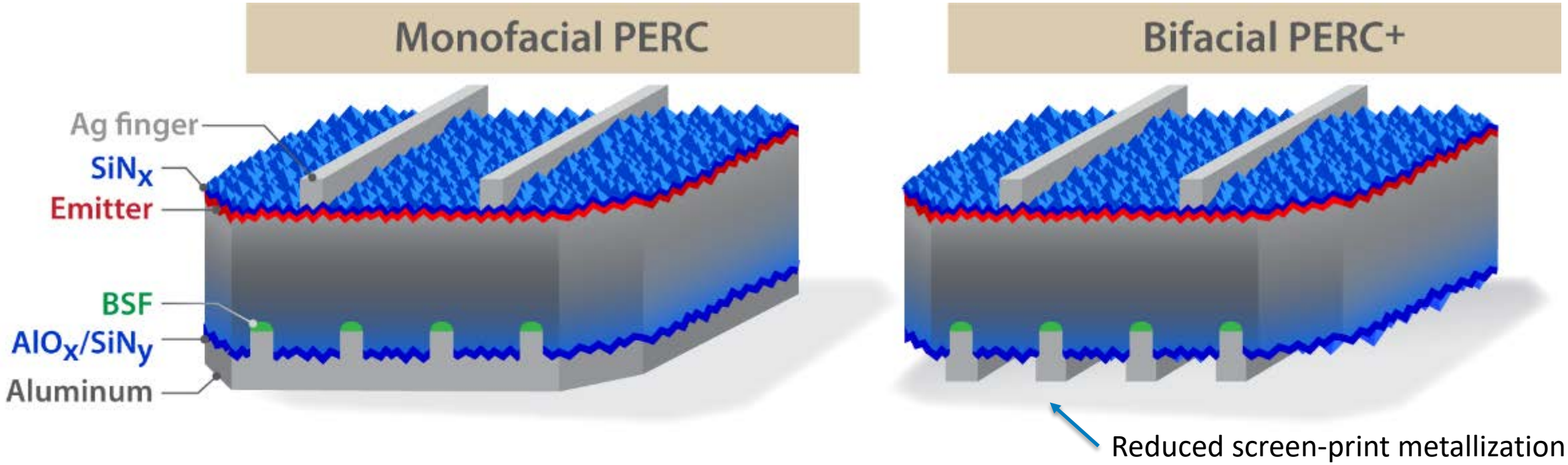
Woods Mackenzie Global bifacial market report, September 2019

Bifacial market needs (~2016)

The PV industry is set for rapid uptake of bifacial PV if key barriers are eliminated

- accurate performance models
- reliability standards and STC rating of bifacial modules
- accurate assessment of site albedo
- documented bifacial gains in the field

PERC Cell Technology – Easily Bifacial

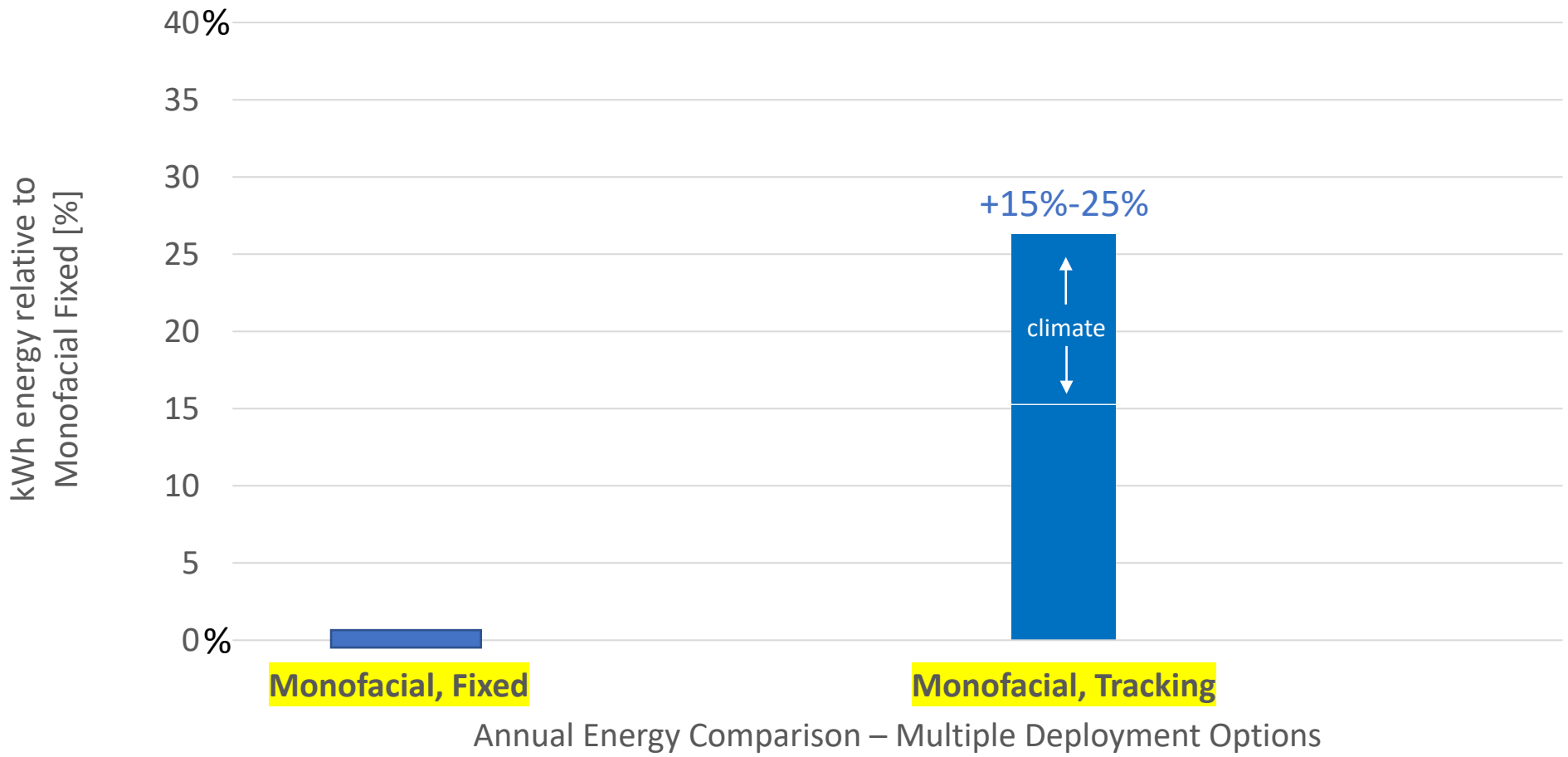


Module bifaciality $\phi = \frac{P_{Rear}}{P_{Front}} =$

0.65–0.80 (p-PERC)	**0.75–0.90 (n-PERT)**	**0.85–0.95 (Si heterojunction)**

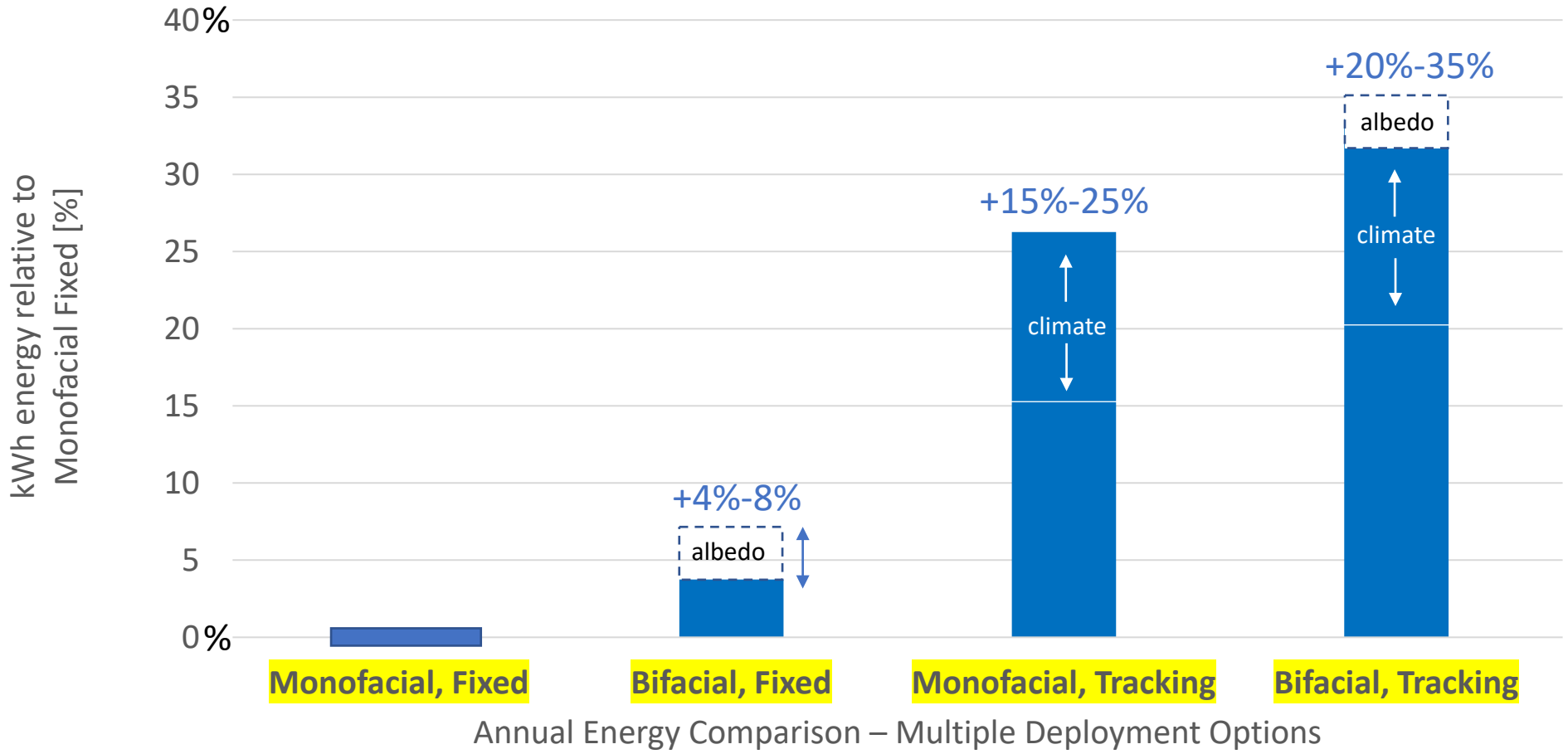
T. Dullweber et al., "PERC+: Industrial PERC solar cells with rear Al grid enabling bifaciality and reduced Al paste consumption," *Prog. Photovolt: Res. Appl.* (2015).

Big Levers on Energy Yield



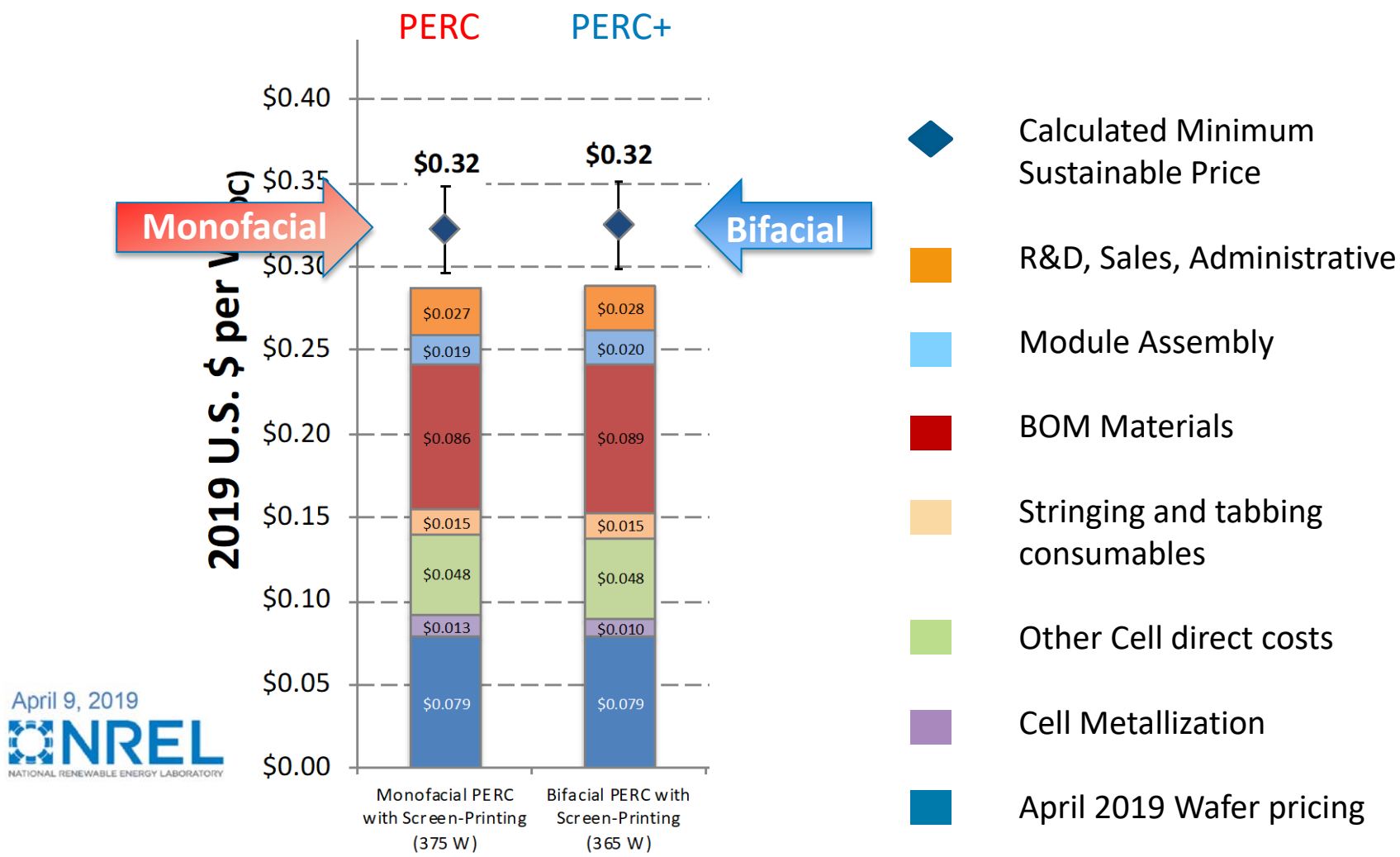
*SAM simulation, range of scenarios

Big Levers on Energy Yield



*SAM simulation, range of scenarios

Bifacial module costs the same as monofacial



Additional details given in: (1) M Woodhouse, B Smith, A Ramdas, and R Margolis "Economic Factors of Production Affecting Current and Future Crystalline Silicon Photovoltaic Module Manufacturing Costs and Sustainable Pricing", *In preparation.* (2) A Faes, C Ballif, M Despeisse, et al, "Metallization and interconnection for high efficiency bifacial silicon heterojunction solar cells and modules", *Photovoltaics International,* 3, 1—12 (2018) (3) A Louwen, W van Sark, R Schropp, and A Faaij, "A Cost Roadmap for silicon heterojunction solar cells", Solar Energy Materials and Solar Cells, 147, 295—314 (2016)

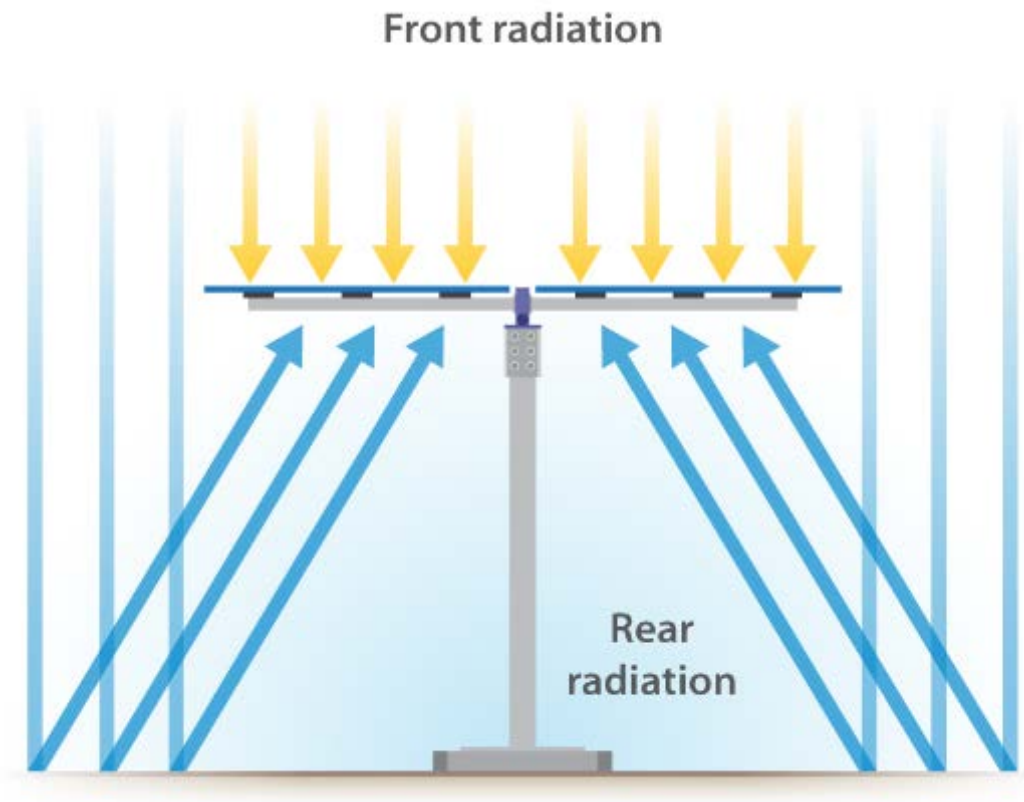
Bifacial Performance

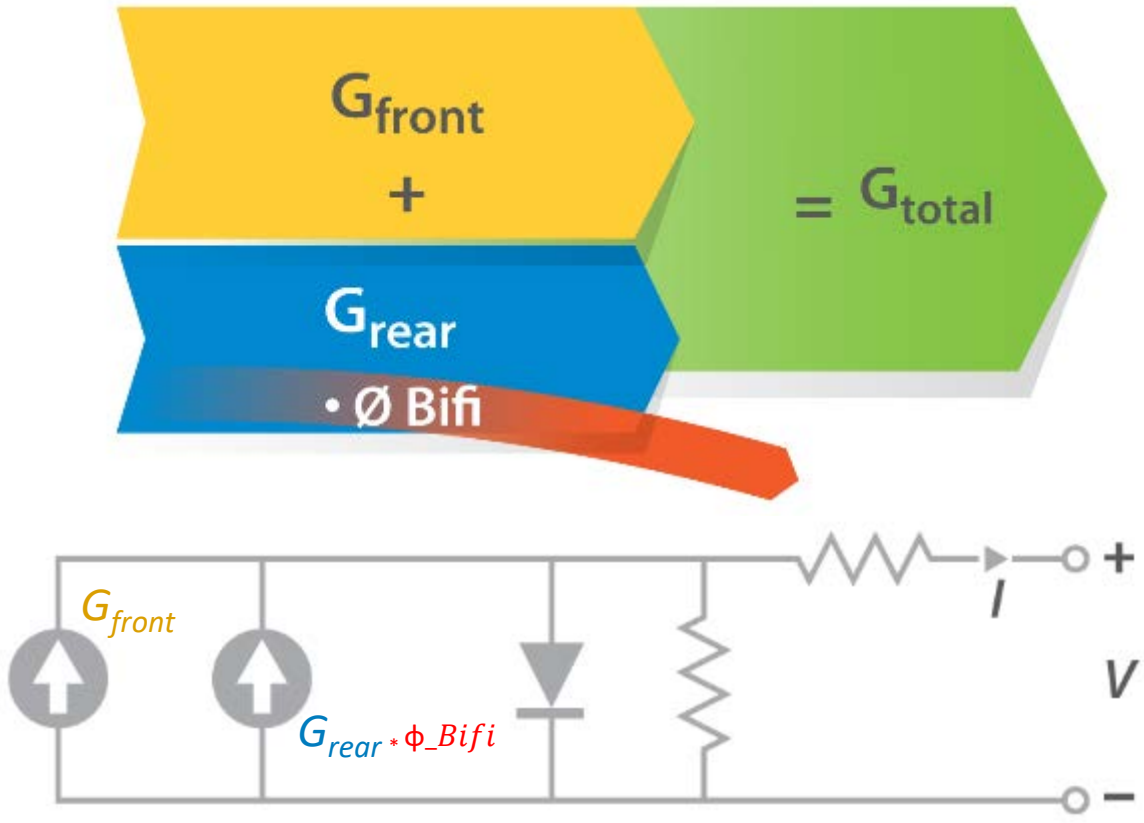
Overview

Photo credit: Prism Solar

Bifacial Total Irradiance

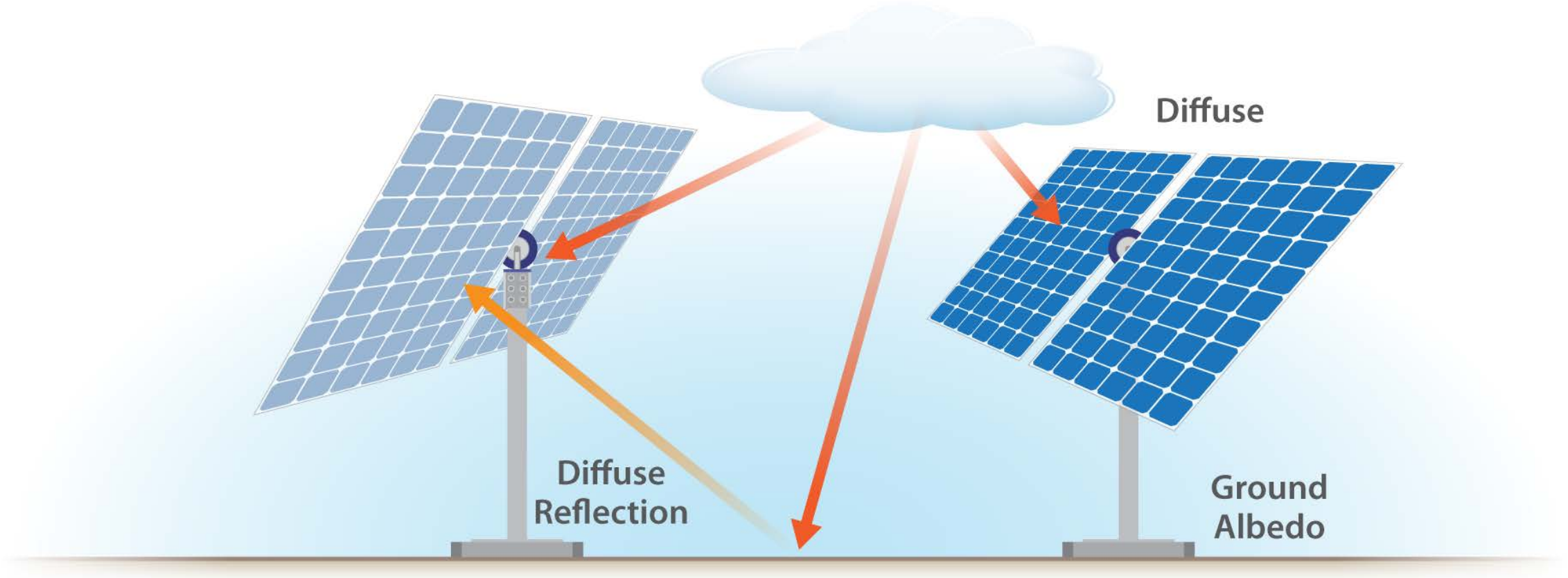
$$G_{Total} = G_{Front} + (G_{Rear}) \times (\boldsymbol{bifaciality}) \times (1 - \eta_{Loss})$$





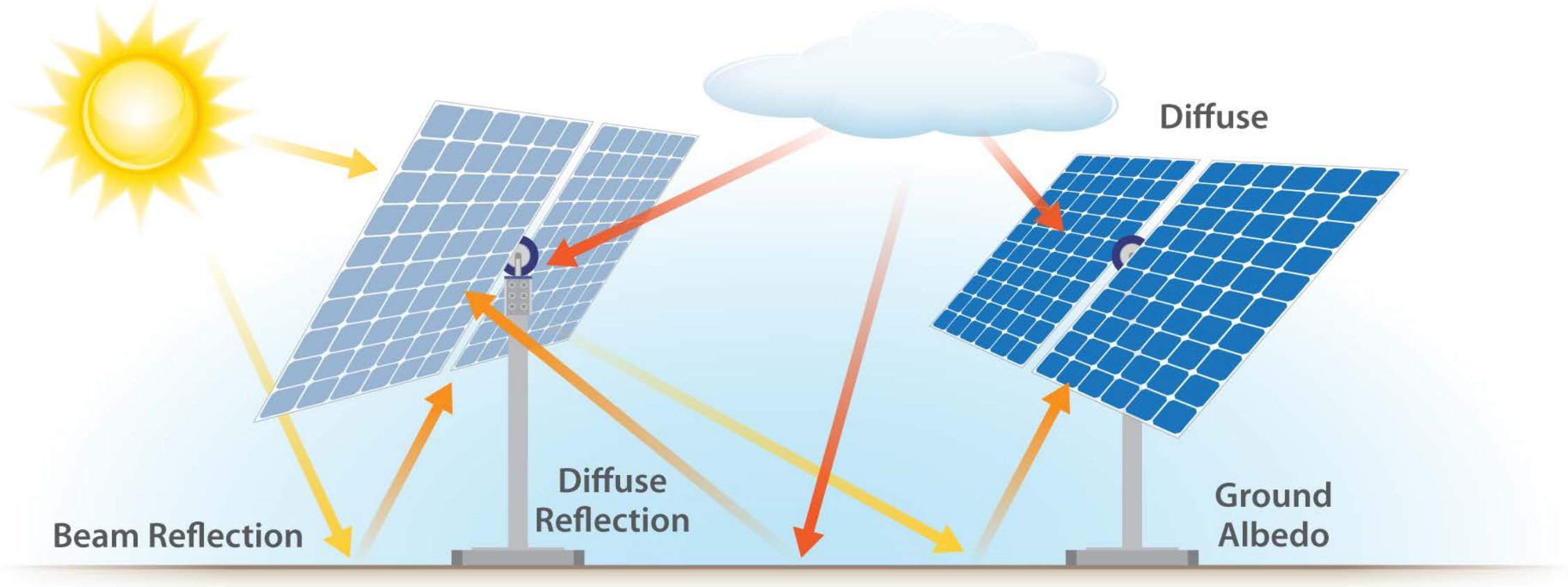
Module bifaciality $\boldsymbol{\phi_{Bifi}} = \dfrac{Pmp_0\ rear}{Pmp_0\ front}$

Modeling Rear Irradiance



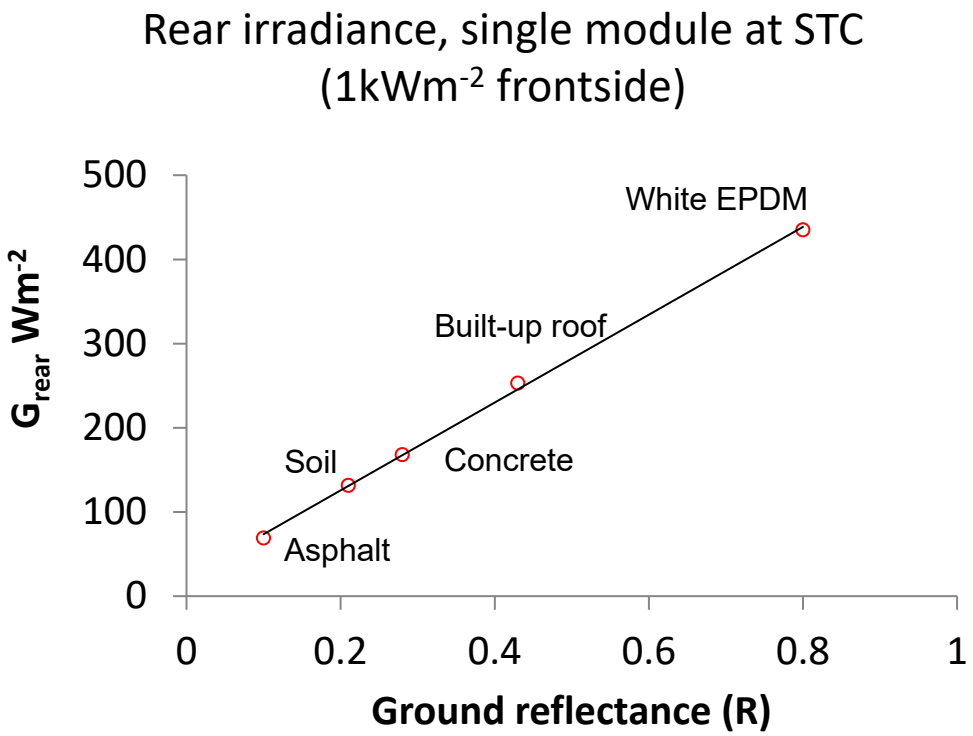
$$G_{rear} = G_{diffuse,r} + G_{reflected,r} + G_{beam,r}$$

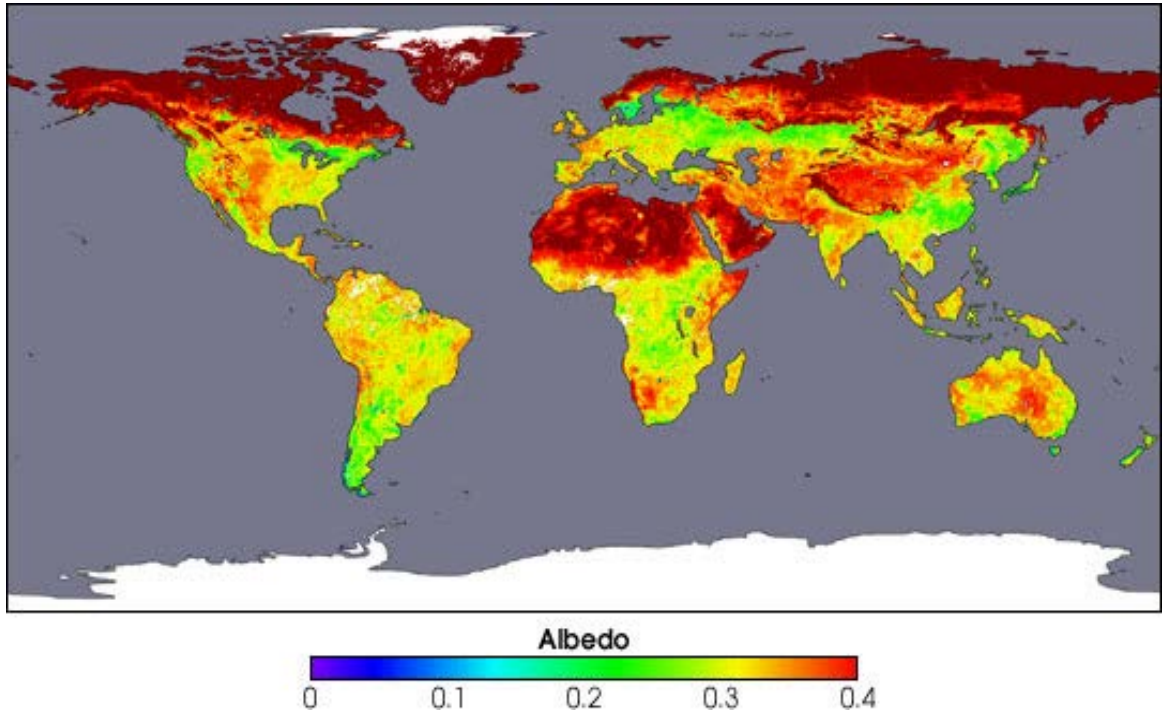
Modeling Rear Irradiance



$$G_{rear} = G_{diffuse,r} + G_{reflected,r} + G_{beam,r}$$

Surface Albedo has a big effect

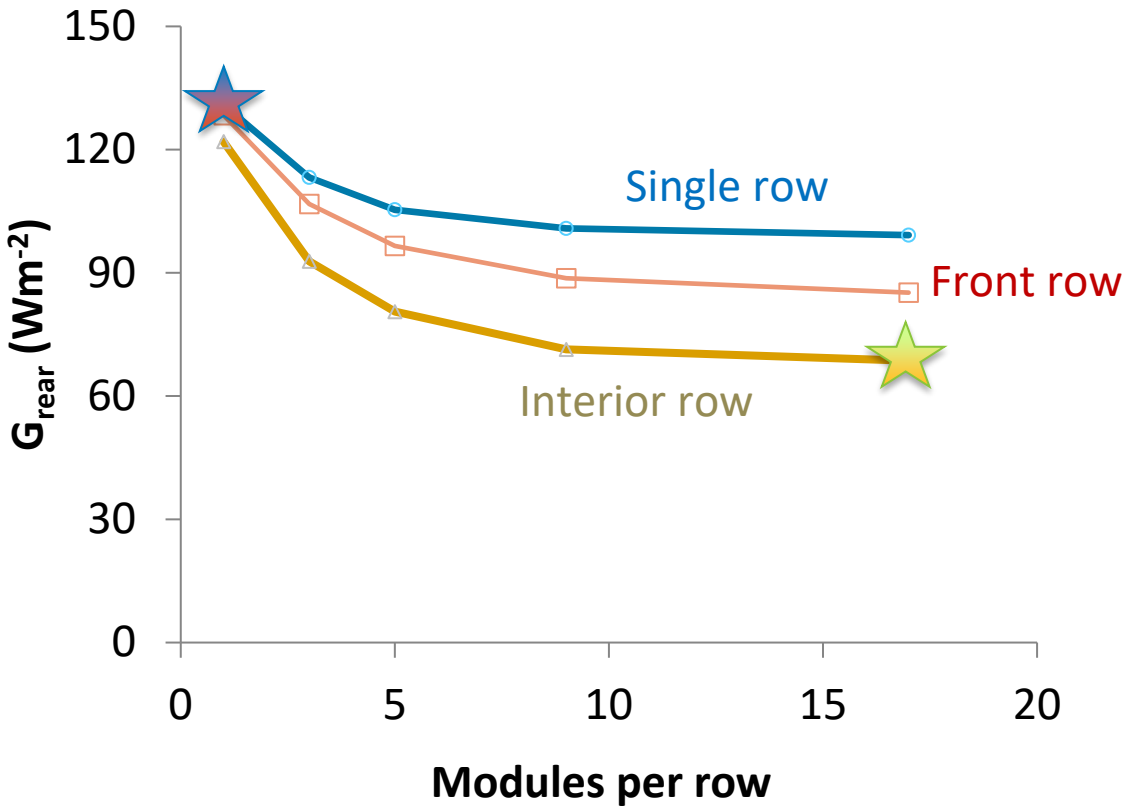


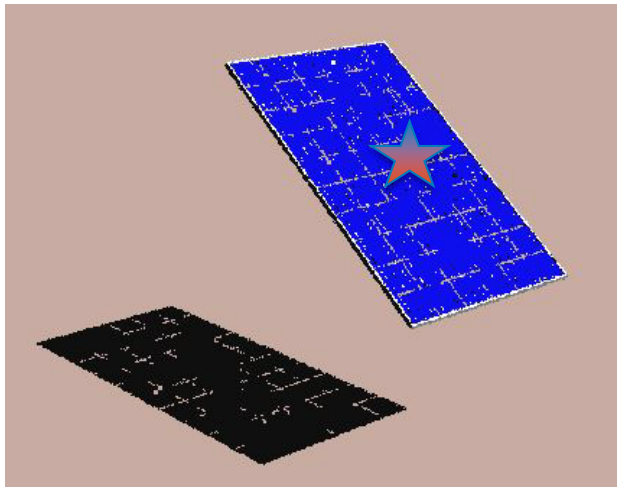


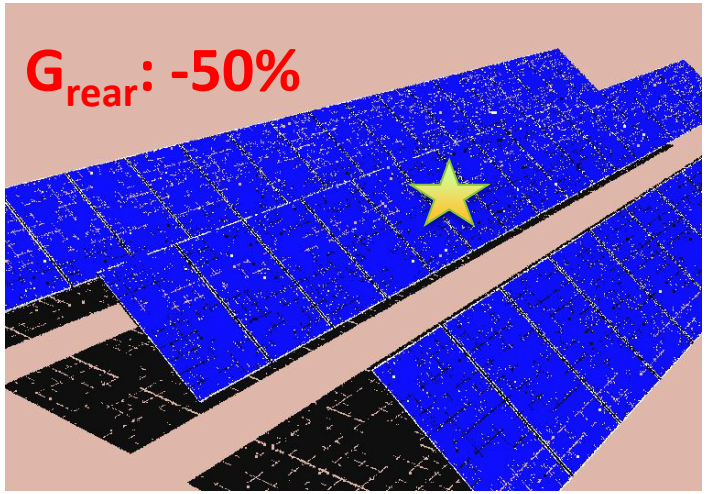
NASA Earth Observations, https://neo.sci.gsfc.nasa.gov/view.php?datasetId=MCD43C3_M_BSA

R. Kopecek and J. Libal, Bifacial Photovoltaics: Technology, applications and economics, IET publishing, 2019

System G_{Rear} experiences self-shading







C. Deline et al., Assessment of Bifacial Photovoltaic Module Power Rating Methodologies – Inside and Out, J. Photovoltaics **7,** 2017


Bifacial trackers, 75 kW
Five bifacial technologies

Bifacial system configuration

- 20 modules (7.5 kW) / row
- **4 PERC, 1 SHJ Bifacial strings**
- 3 PERC monofacial strings
- Module electronics / monitoring
- String kWh_{DC} monitoring
- Front, rear POA irradiance

Bifacial system configuration

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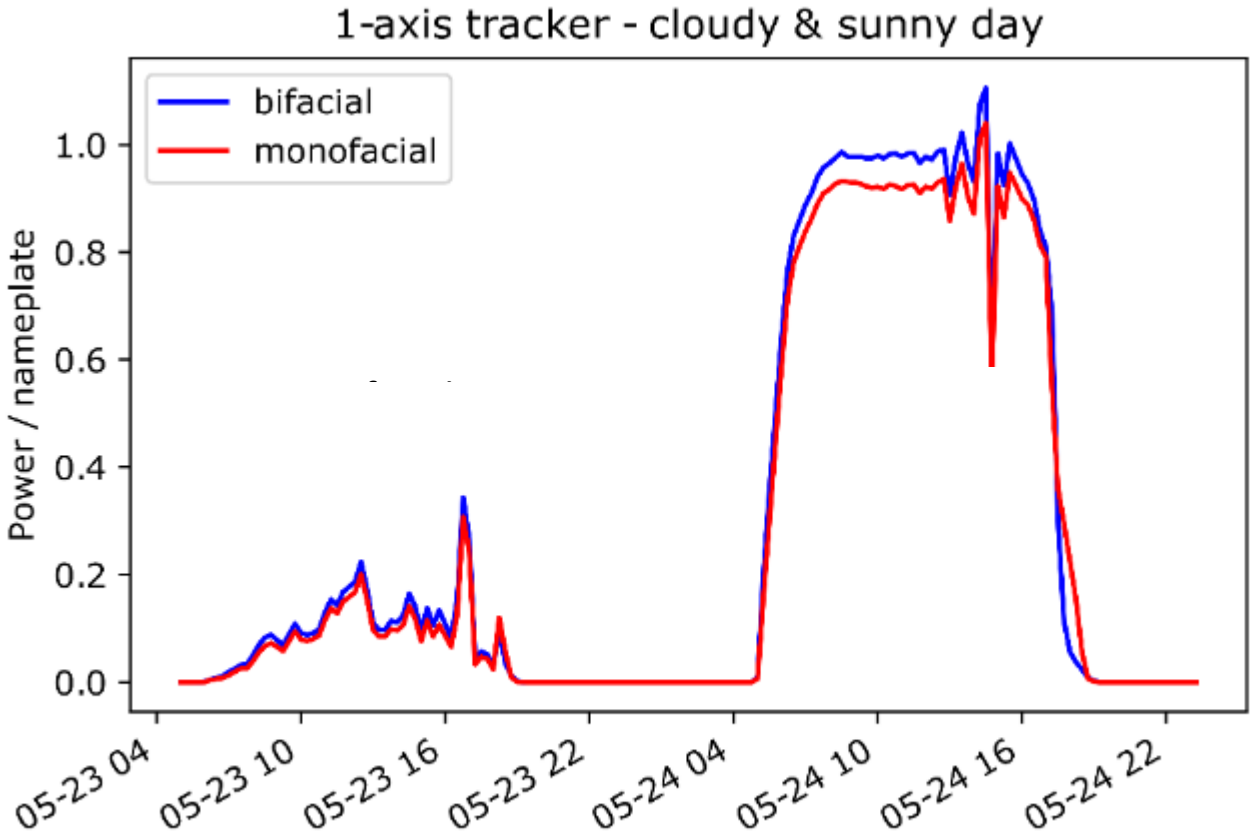
- String kWh_{DC} monitoring
- **Front, rear POA irradiance**

= Front POA

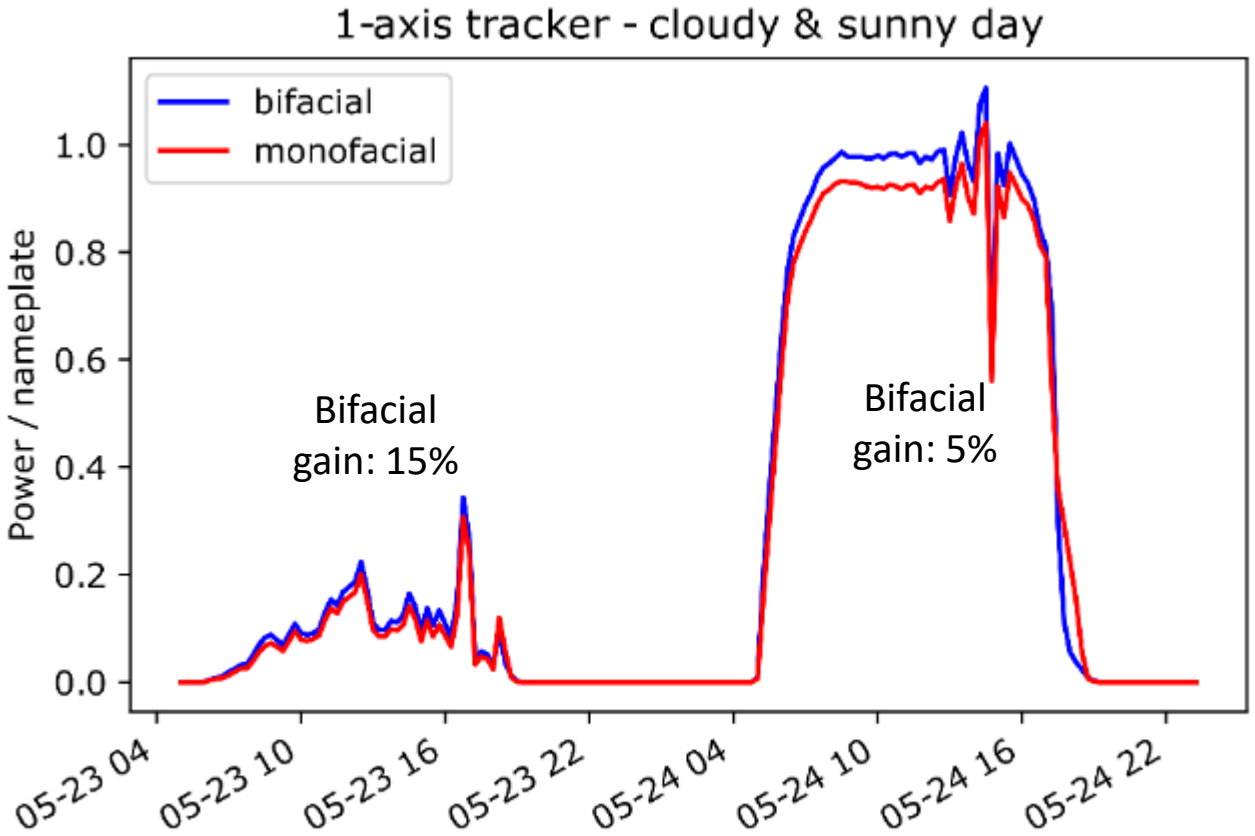
= Rear POA

Initial Field Results – Bifacial Trackers



$$BG_E = \frac{E_{bifacial}}{E_{mono}} - 1$$

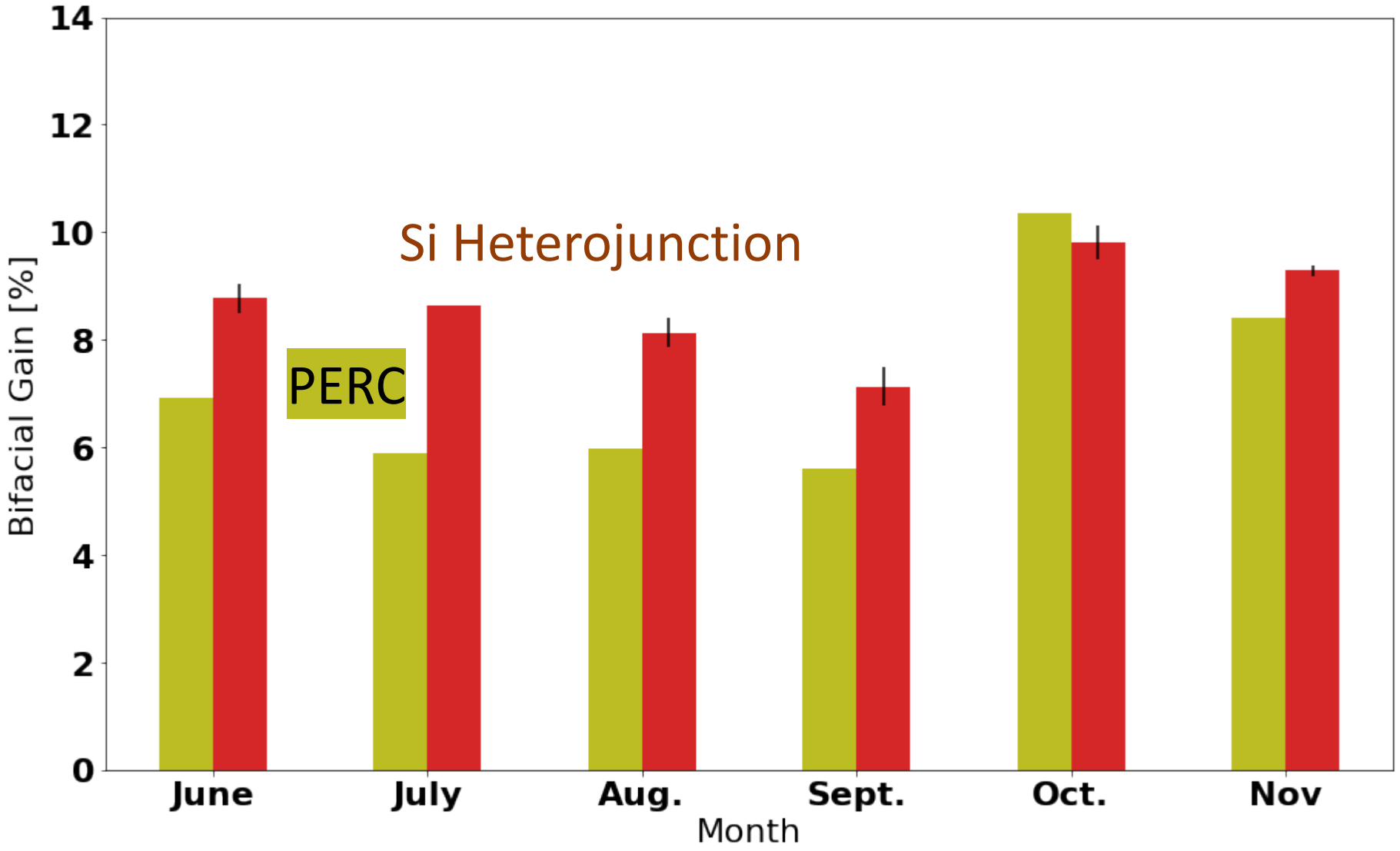
Initial Field Results – Bifacial Trackers



$$BG_E = \frac{E_{bifacial}}{E_{mono}} - 1$$

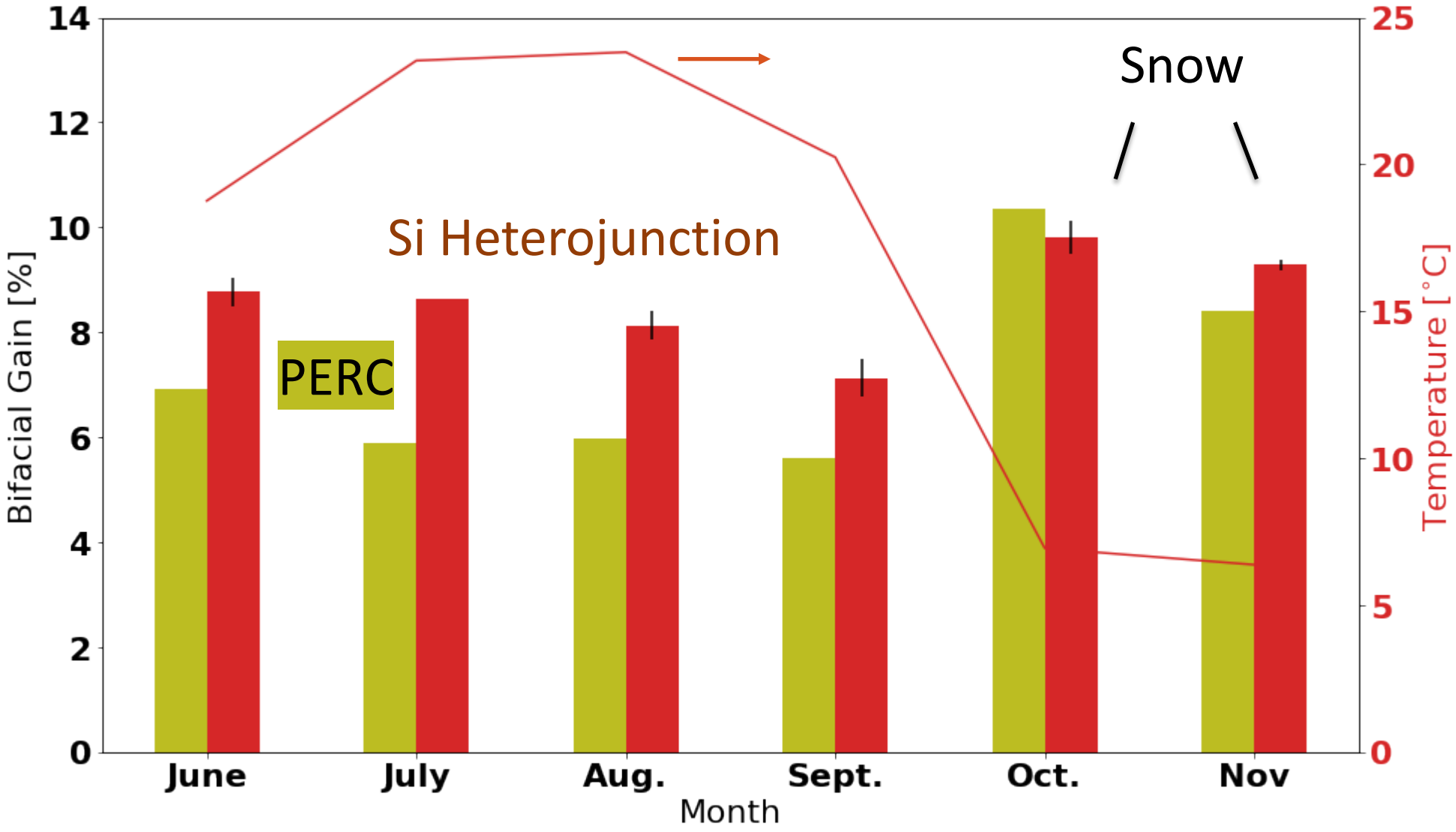
Monthly Bifacial Energy Gain

$$BG_E = \frac{E_{bifacial}}{E_{mono}} - 1$$



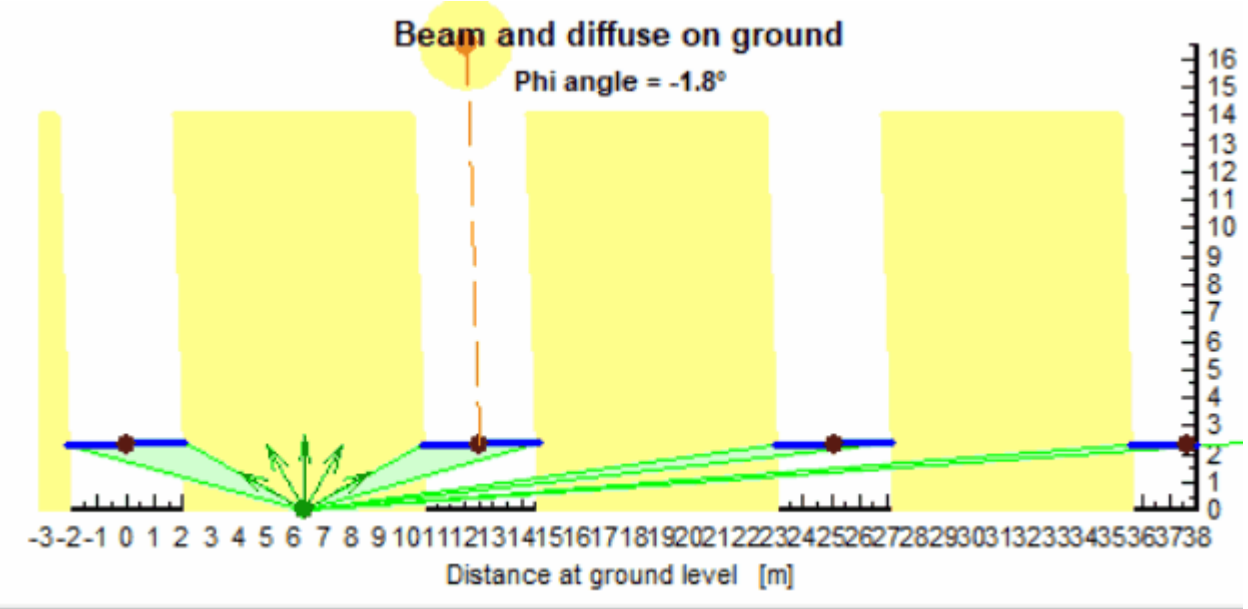
Monthly Bifacial Energy Gain

$$BG_E = \frac{E_{bifacial}}{E_{mono}} - 1$$



Modeled Bifacial Performance

View Factor Models for Rear Irradiance



PVSyst v6.8.4

SAM 2018.11.11

Simple

Basic
Geometry

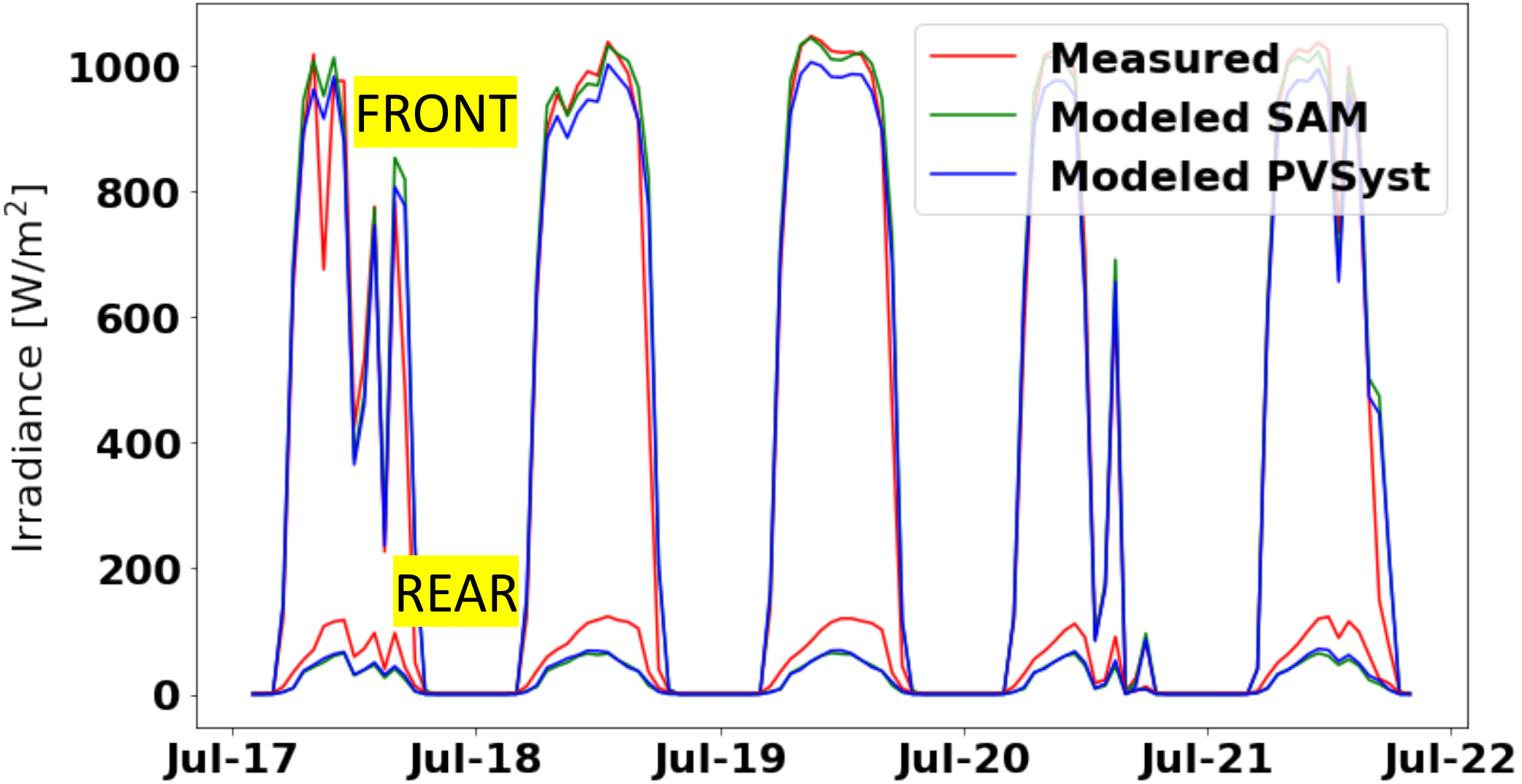
Fast

Computationally
Inexpensive

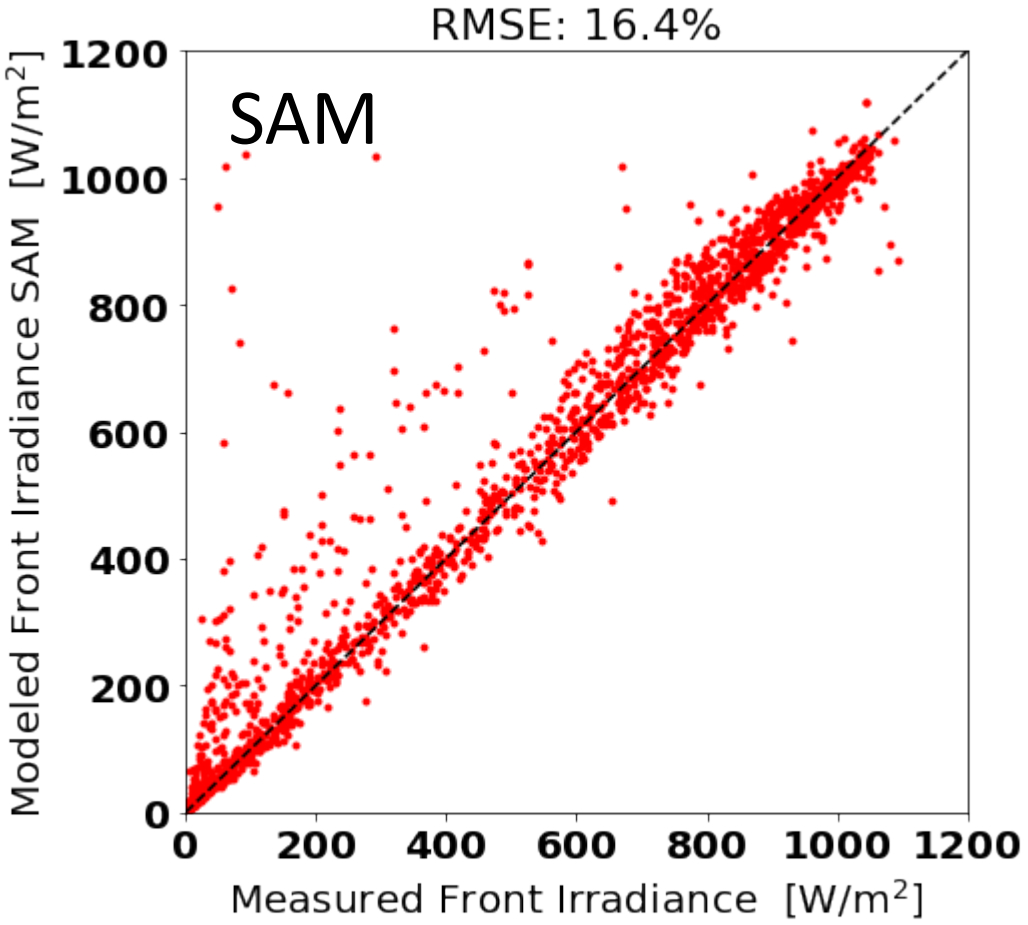
Common

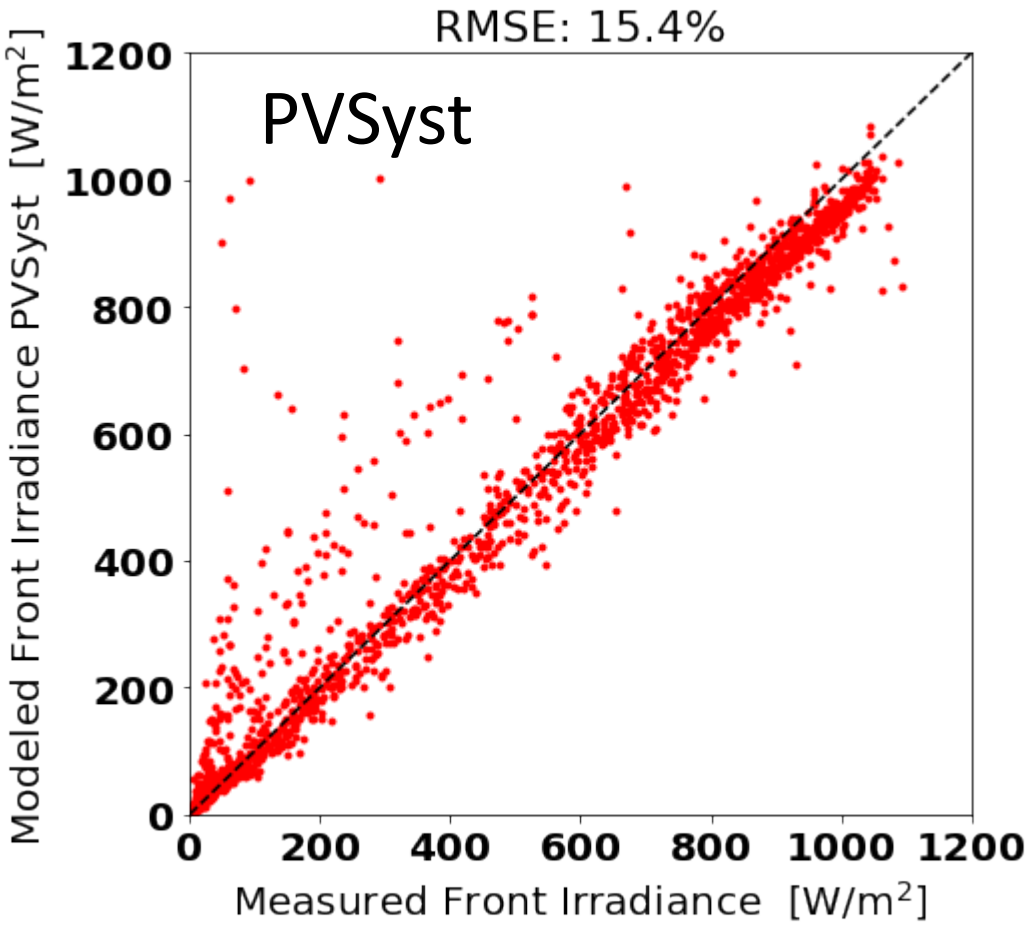
Behind
SAM, PVSyst, and others

Measured vs Modeled Irradiances



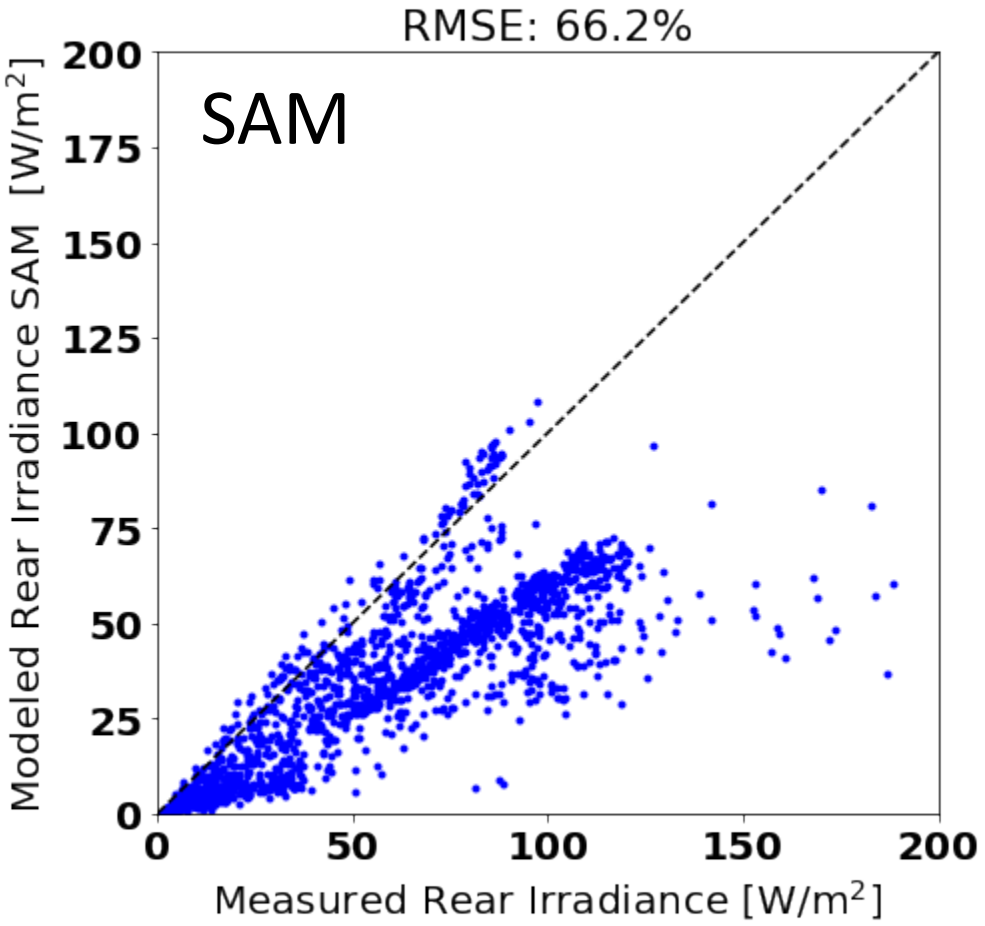
Measured vs Modeled Irradiance July to November 21st

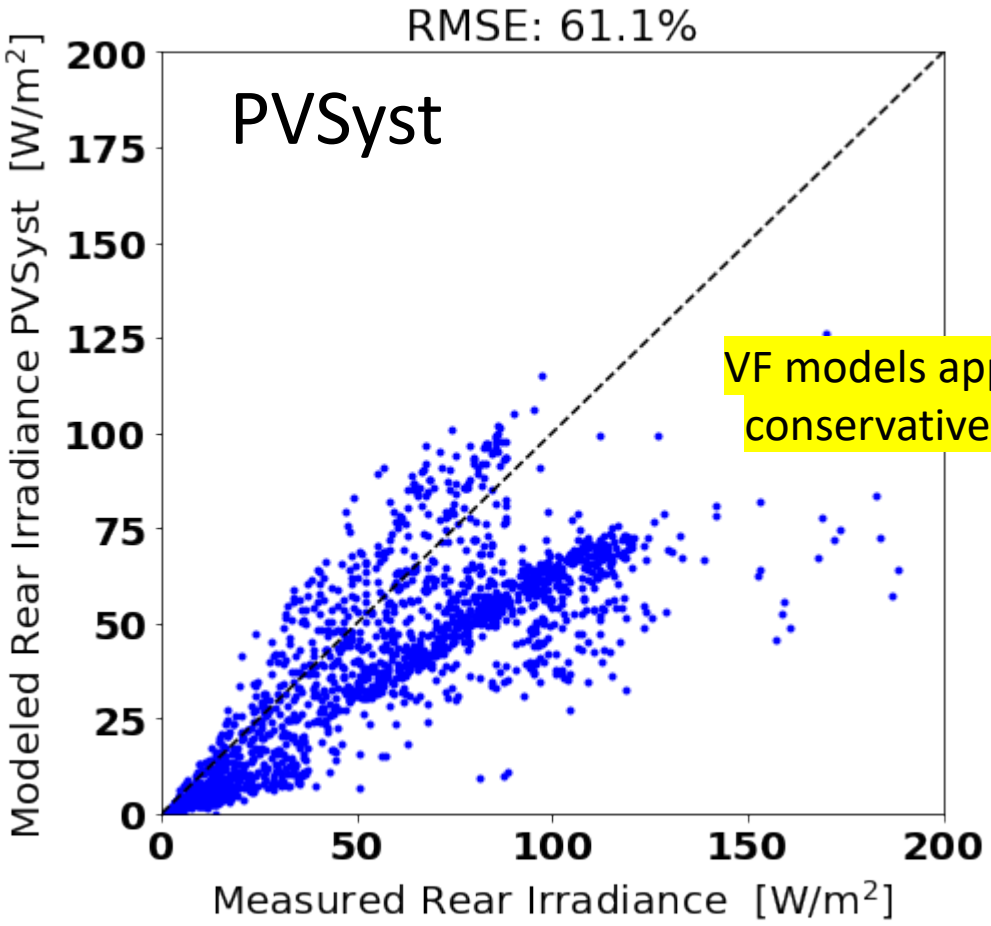




FRONT

Measured vs Modeled Irradiance July to November 21st



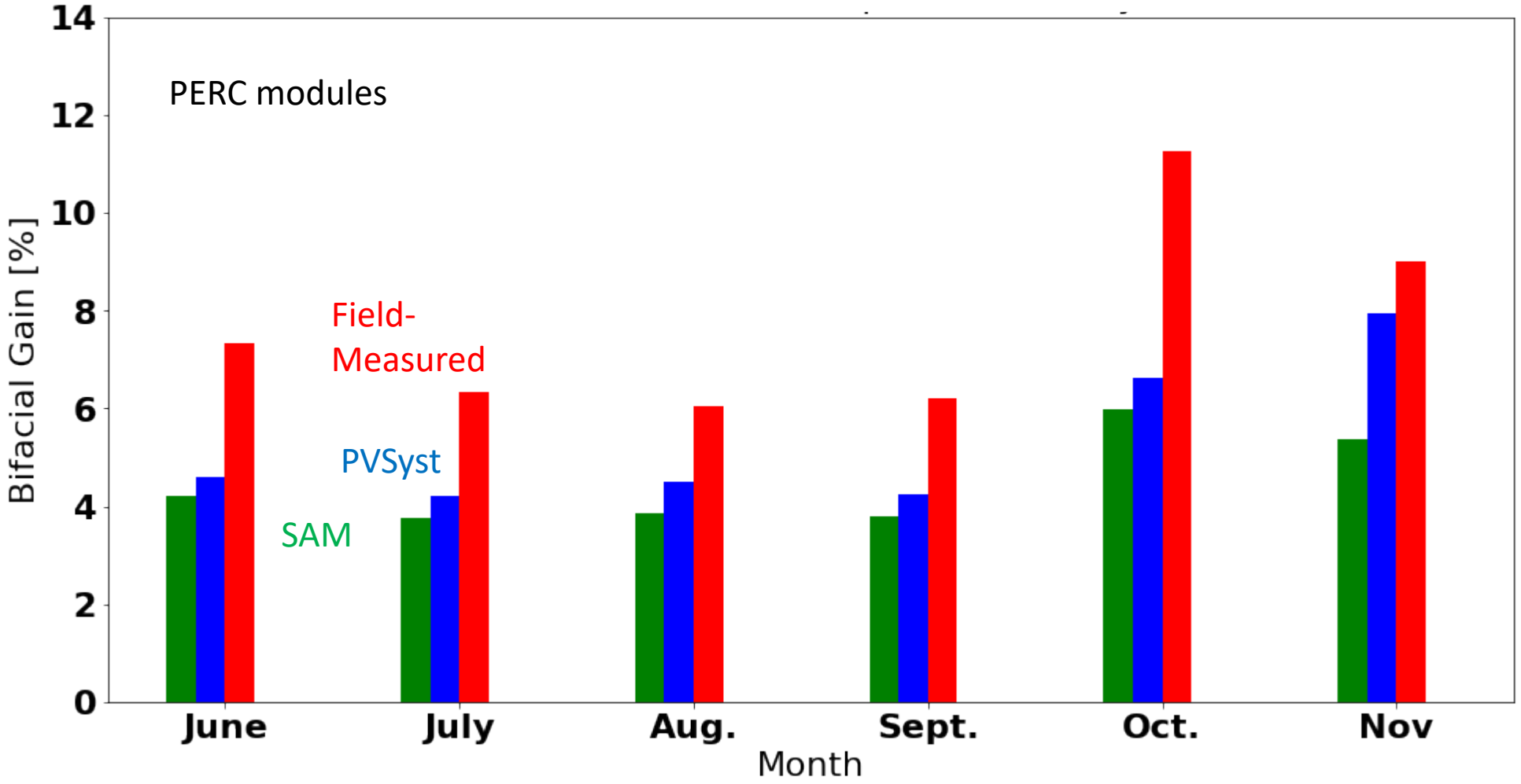


VF models appear to be conservative by ~30%

REAR

Monthly Bifacial Gain
Measured vs. Modeled

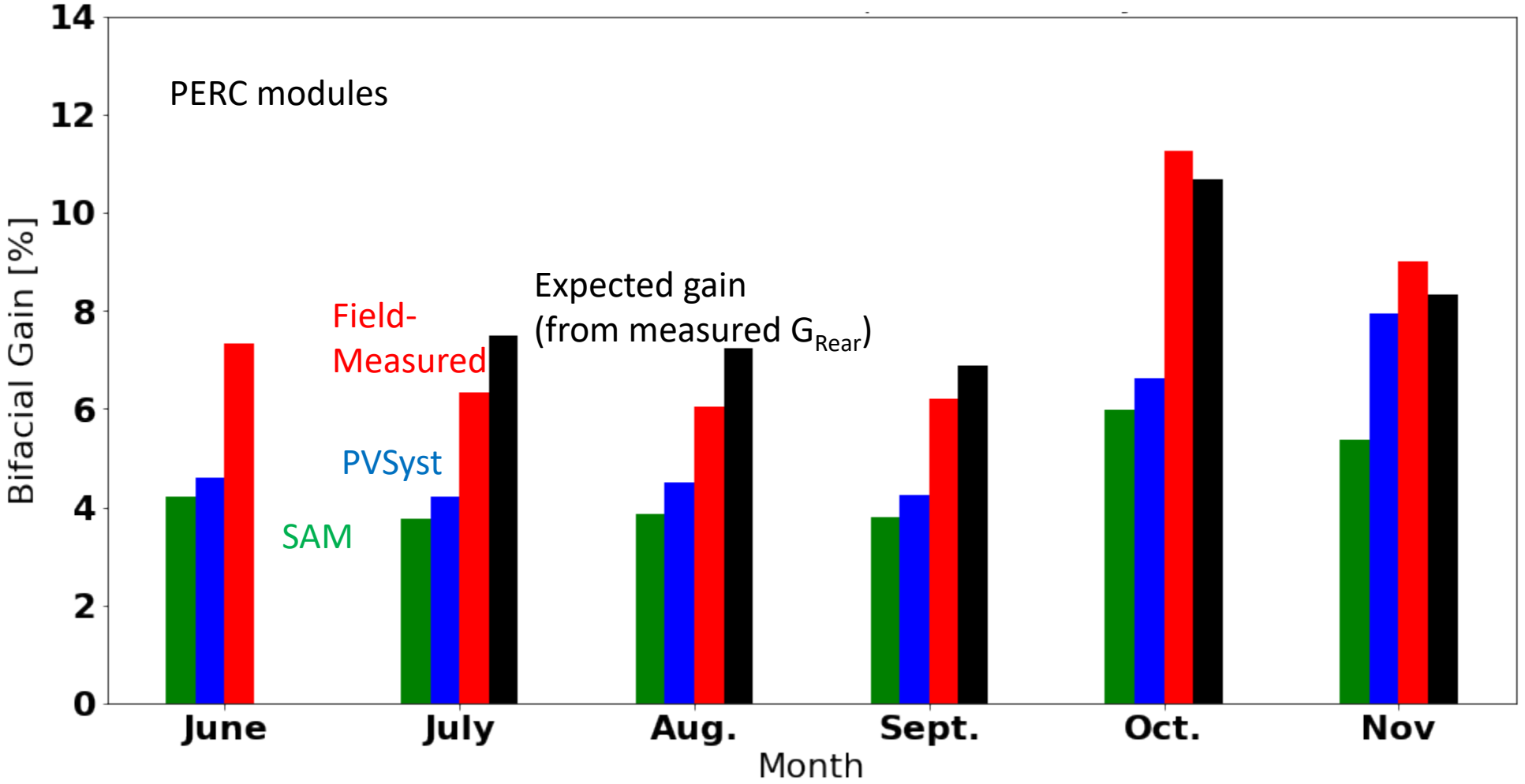
$$BG_E = \frac{E_{bifacial}}{E_{mono}} - 1$$

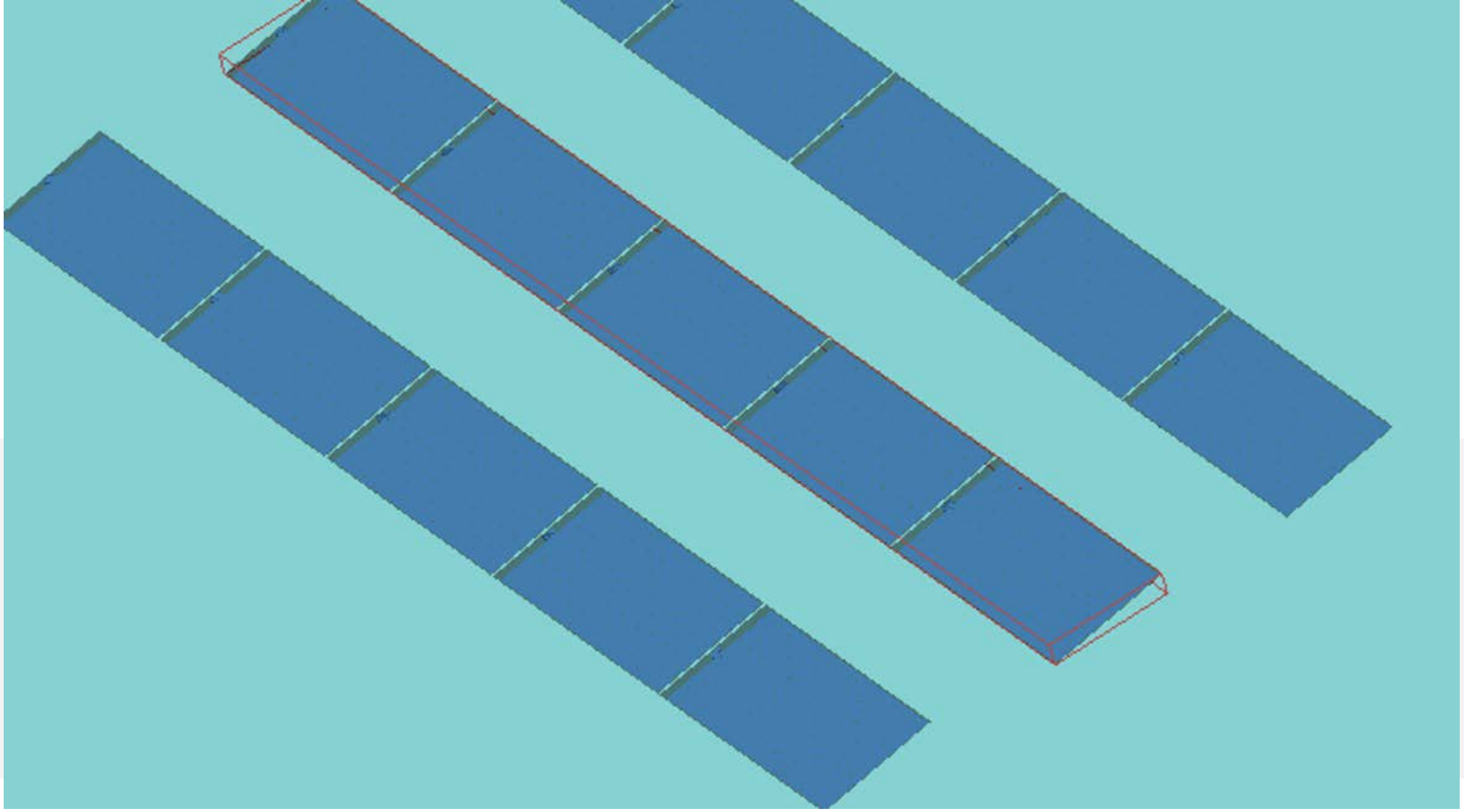


Monthly Bifacial Gain
Measured vs. Modeled

$$BG_E = \frac{E_{bifacial}}{E_{mono}} - 1$$

$$BG_{Irradiance} = \frac{G_{Total}}{G_{Front}} - 1$$

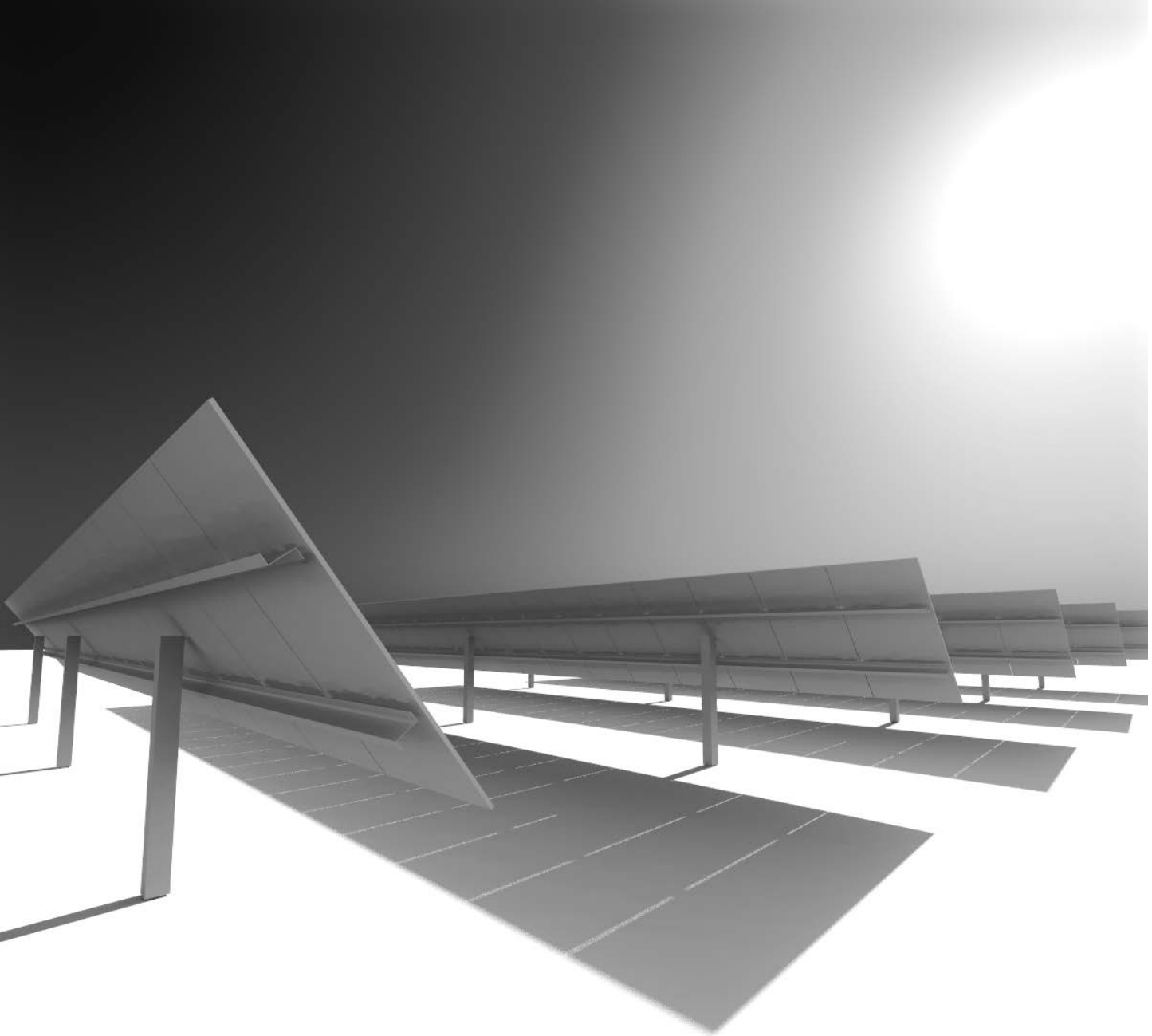




Advanced modeling: Bifacial Raytracing Software

High Performance Computing Integration

Yearly hourly simulations take
4 days on a PC,
HPC RUNS in 1 Minute!



bifacial_radiance

Courtesy of Jason Alderman

Created with NREL bifacial_radiance https://github.com/NREL/bifacial_radiance

Raytrace benefits:

- Any size array
- Sample any module
- Evaluate edge effects
- Complicated geometries
  - Modules
  - Racking
  - Obstructions
- Evaluate shading
- Evaluate electrical mismatch
- Open source
- Dedicated visual interface
- Validated

Cons:

- Complexity ← Visual interface
- Run-times ← Training
  ← HPC integration
  ← Simplified models

Impact of Edges Effects + torquetube shading losses

Raytracing can account for torquetube and edge brightening.

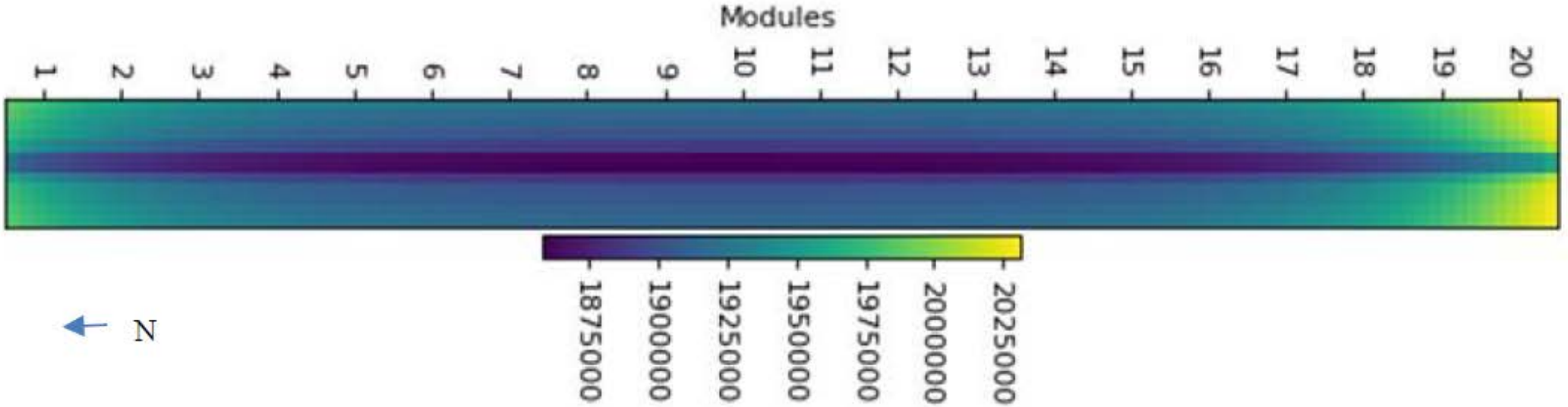
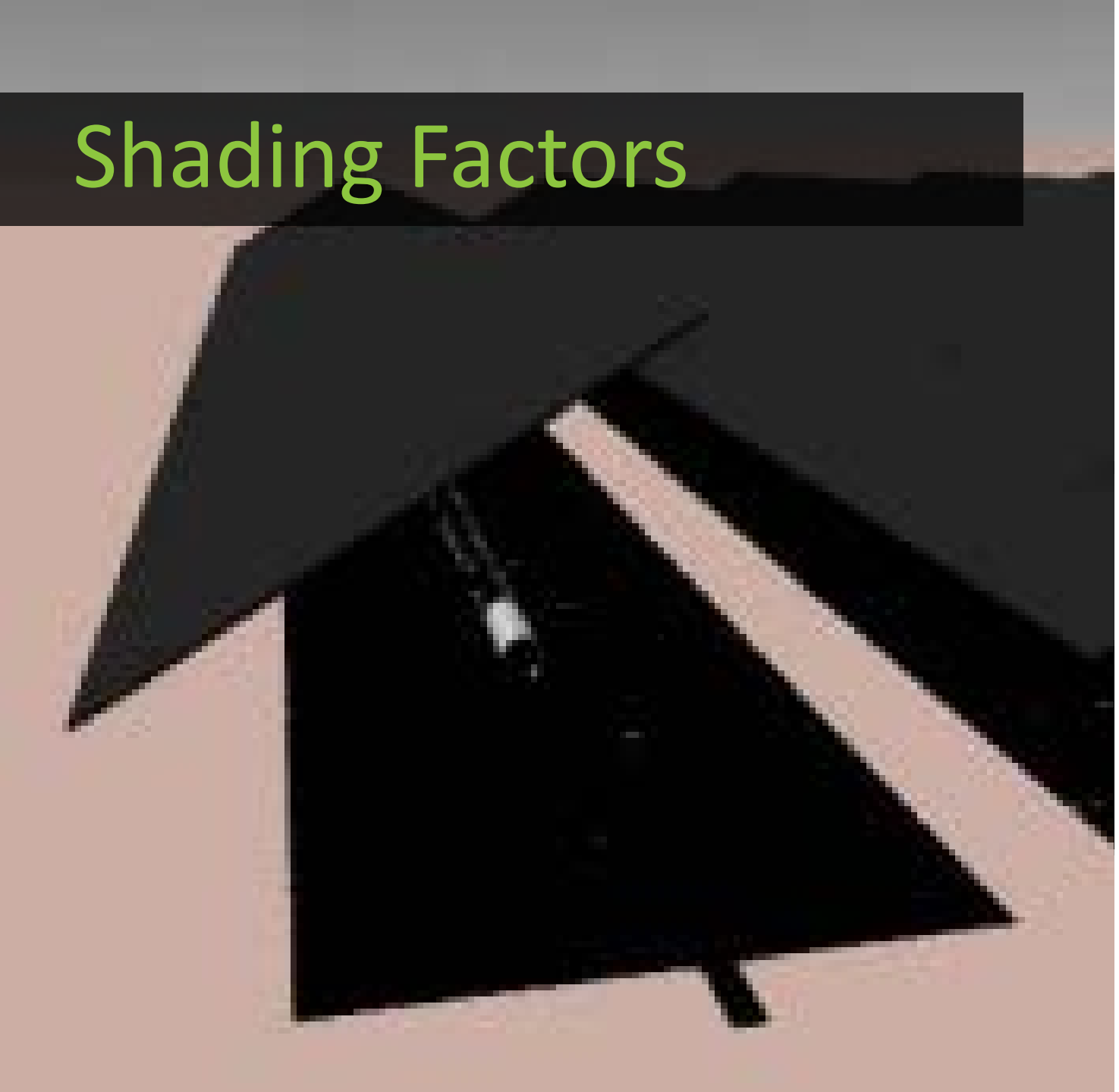


Figure 5 Year cumulative G_{total} [Whm^{-2}] for an interior row of 20 module × 7 rows HSAT at 1.5-m hub height, considering torque tube.

Deline, C., Ayala Pelaez, S., MacAlpine, S., Olalla, C. «Estimating and Parameterizing Mismatch Power Loss in Bifacial Photovoltaic Systems», (Progress in PV, March 2020)

Shading Factors



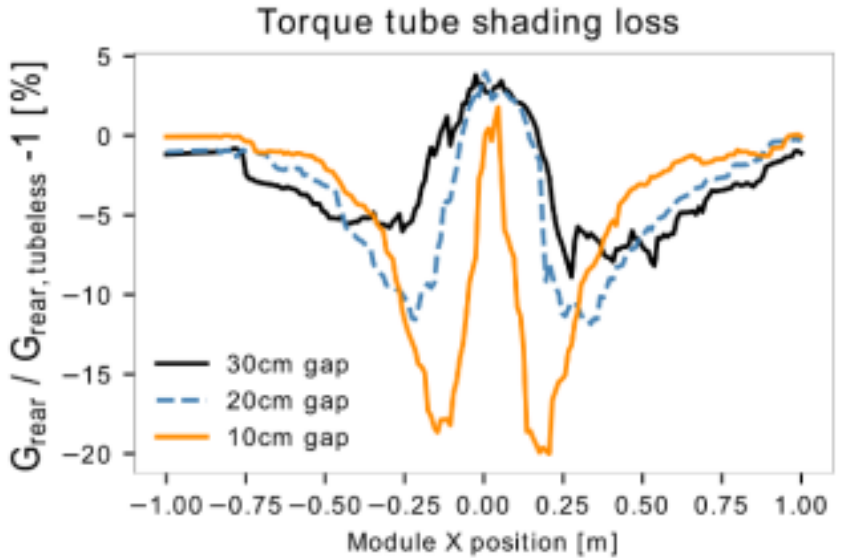
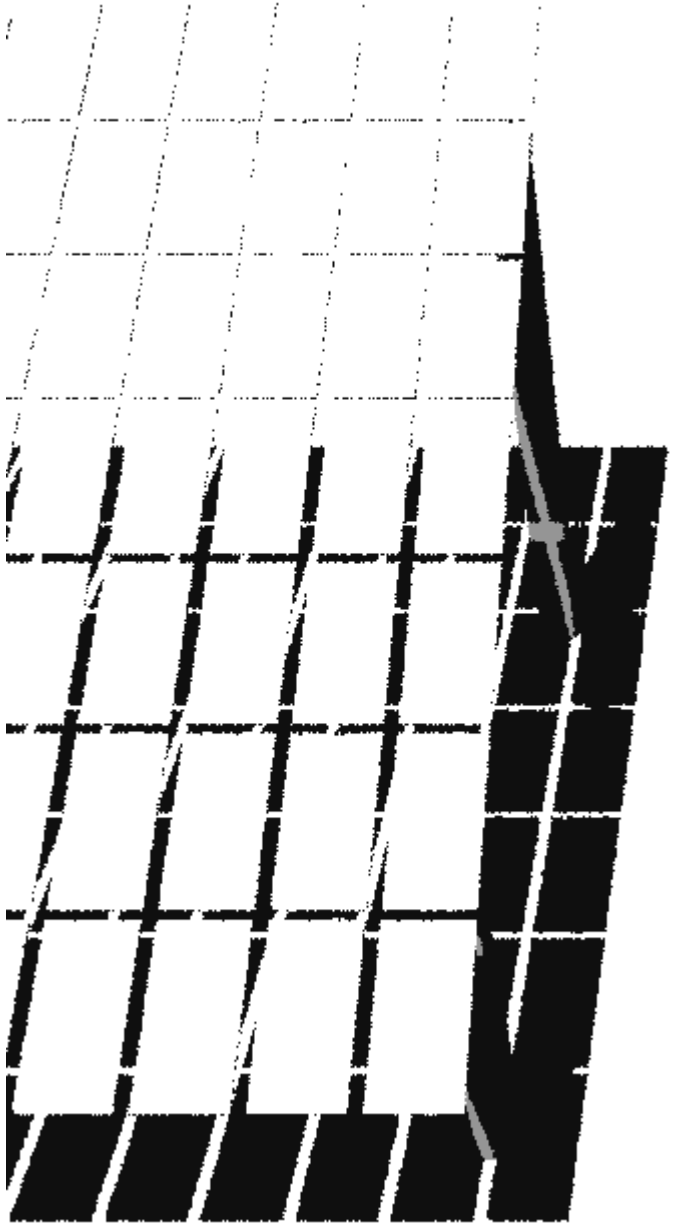


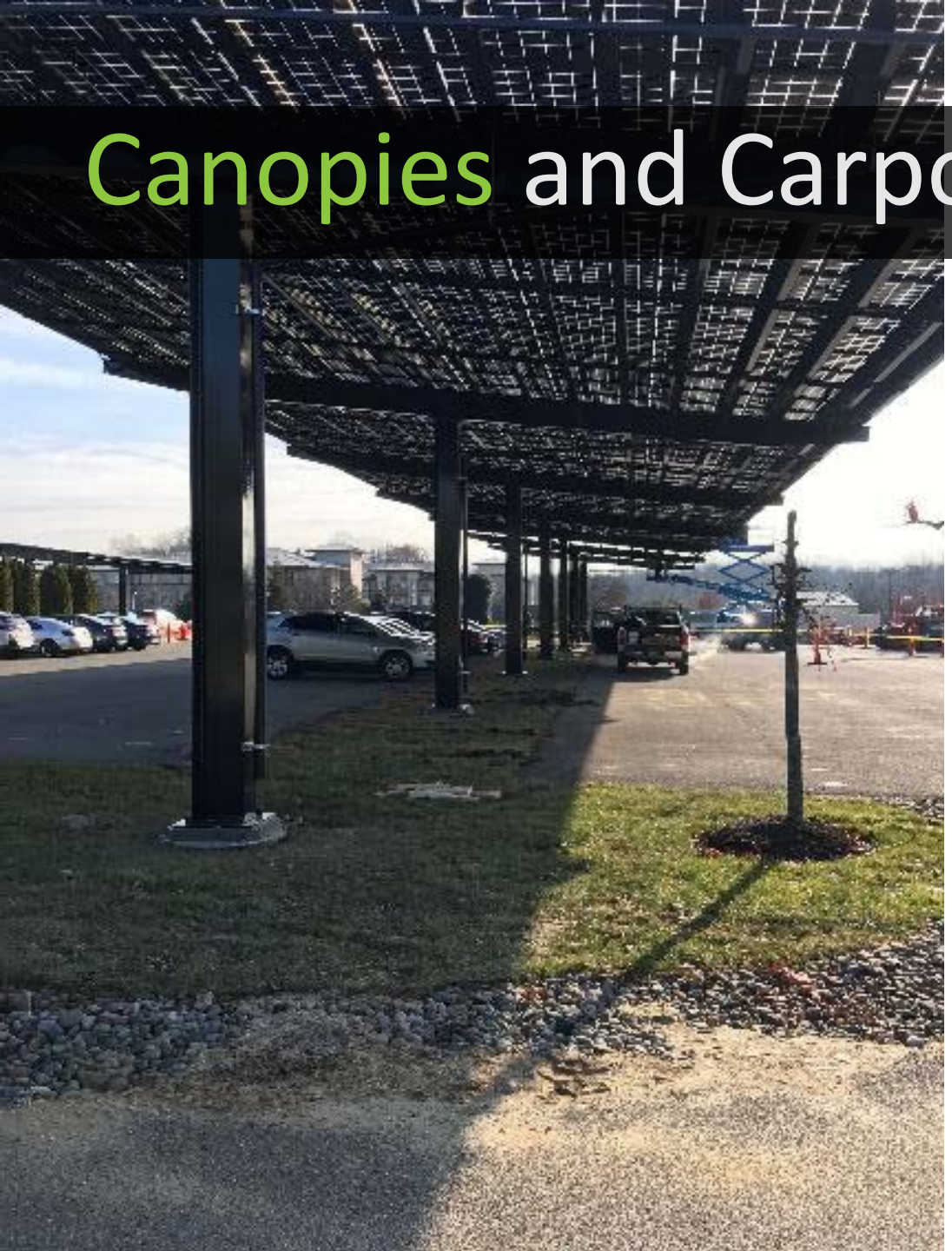
Fig. 13. a) RADIANCE image showing torque tube behind a modules row and b) G_{rear} across the module averaged over a sunny day.

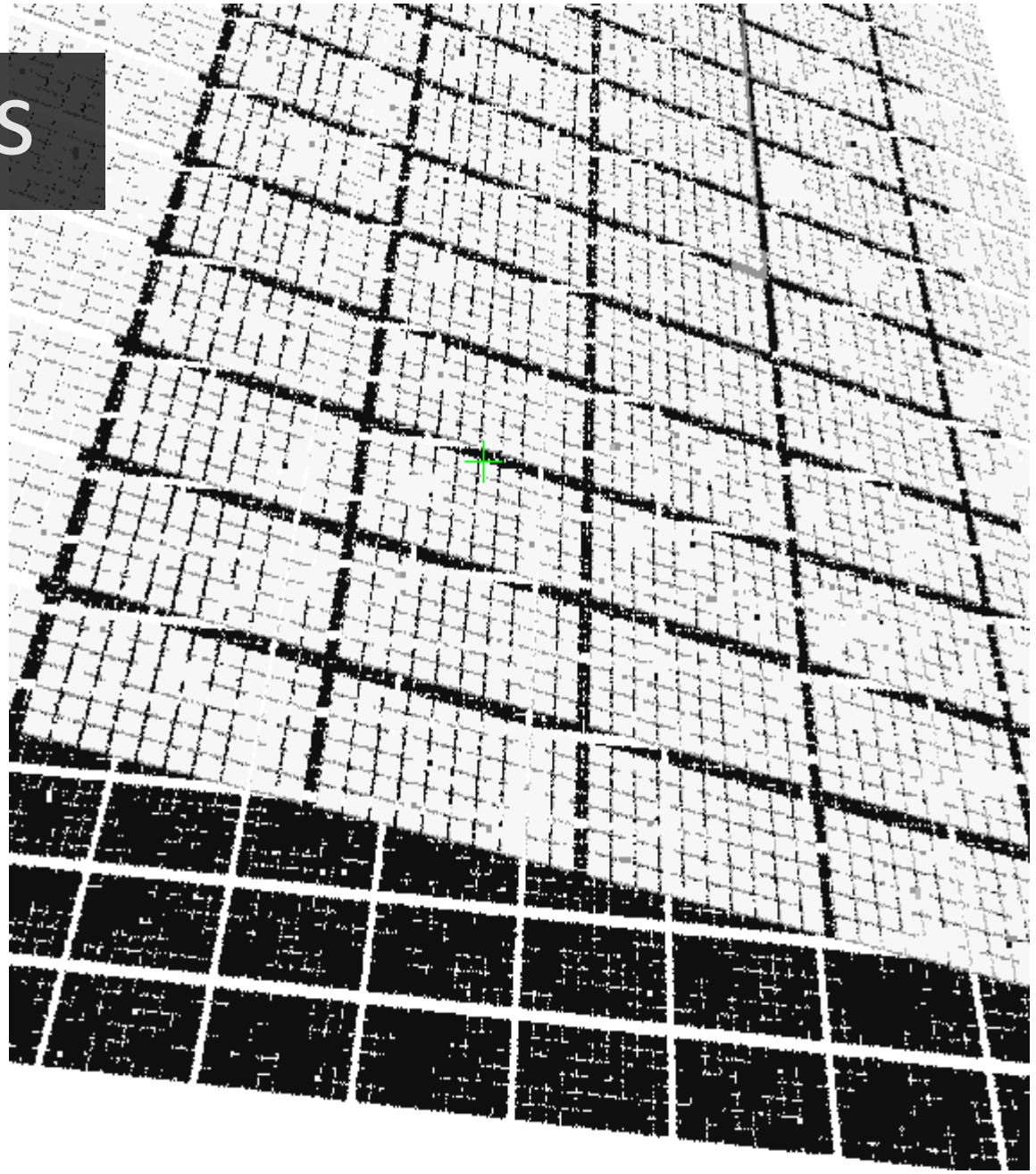
S. Ayala Pelaez et al, "Comparison of Bifacial Solar Irradiance Model Predictions With Field Validation," *IEEE JPV* 2019
https://www.nrel.gov/docs/fy19osti/72039.pdf

Canopies and Carports

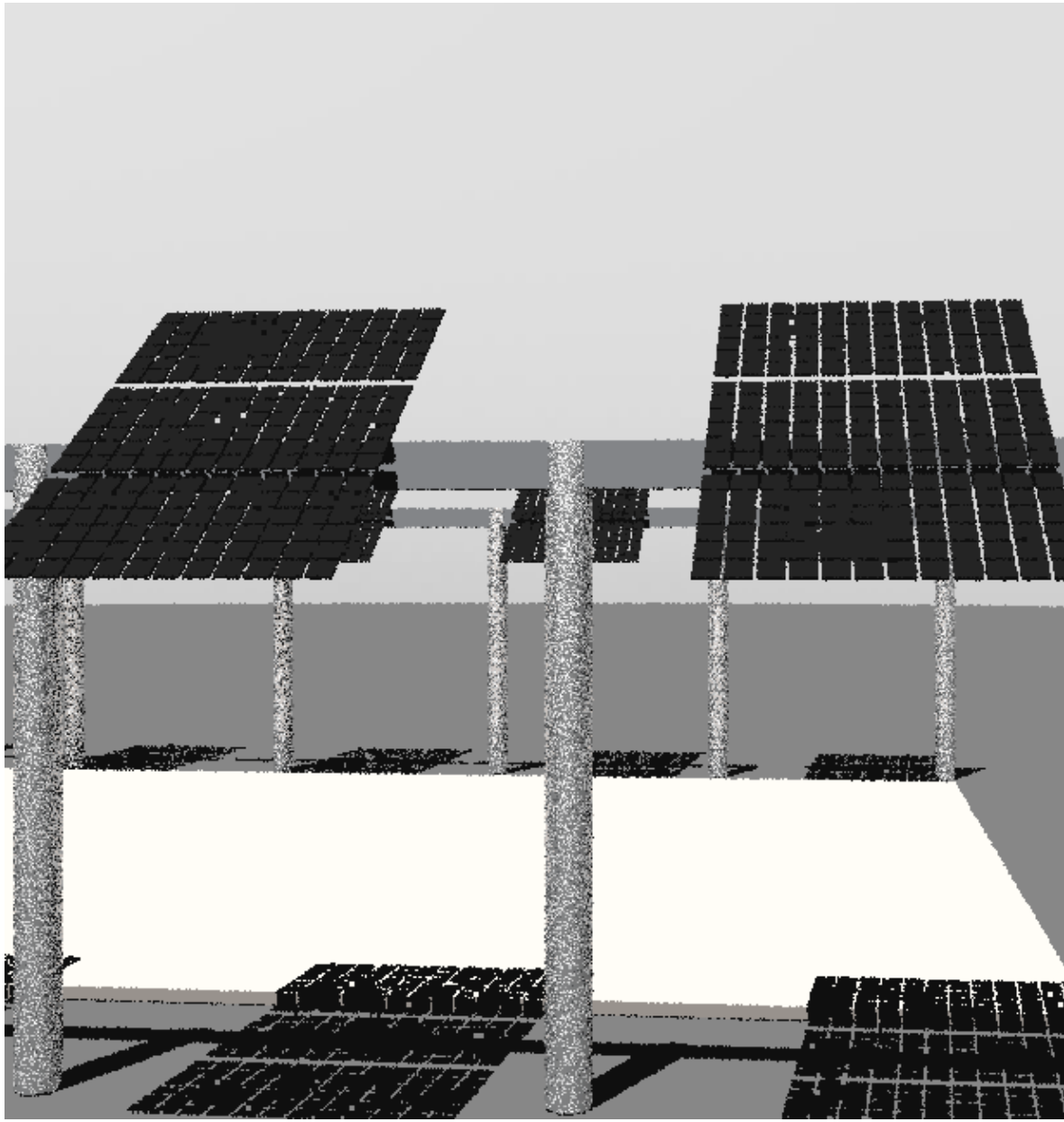


Canopies and Carports





AgriPV



Conclusions

- Bifacial PV is becoming mainstream with gigawatts of installed projects.
- Energy gain depends on the site configuration and surface albedo. Models like SAM, PVSyst, and Bifacial_Radiance can assist with system design and power estimation, although they're somewhat conservative at the moment
- 1-axis tracker validation is underway at NREL and is showing good bifacial annual energy gain of 6.5% and 9% for PERC and Si-HJT, respectively.
- We are working with industry to update codes and standards for bifacial modules and systems

Thank you

www.nrel.gov

chris.deline@nrel.gov
silvana.ayala@nrel.gov

NREL/PR-5K00-76777

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