Measuring and Modeling Bifacial Technologies

bifiPV 2022, 04/01/22 Konstanz-virtual

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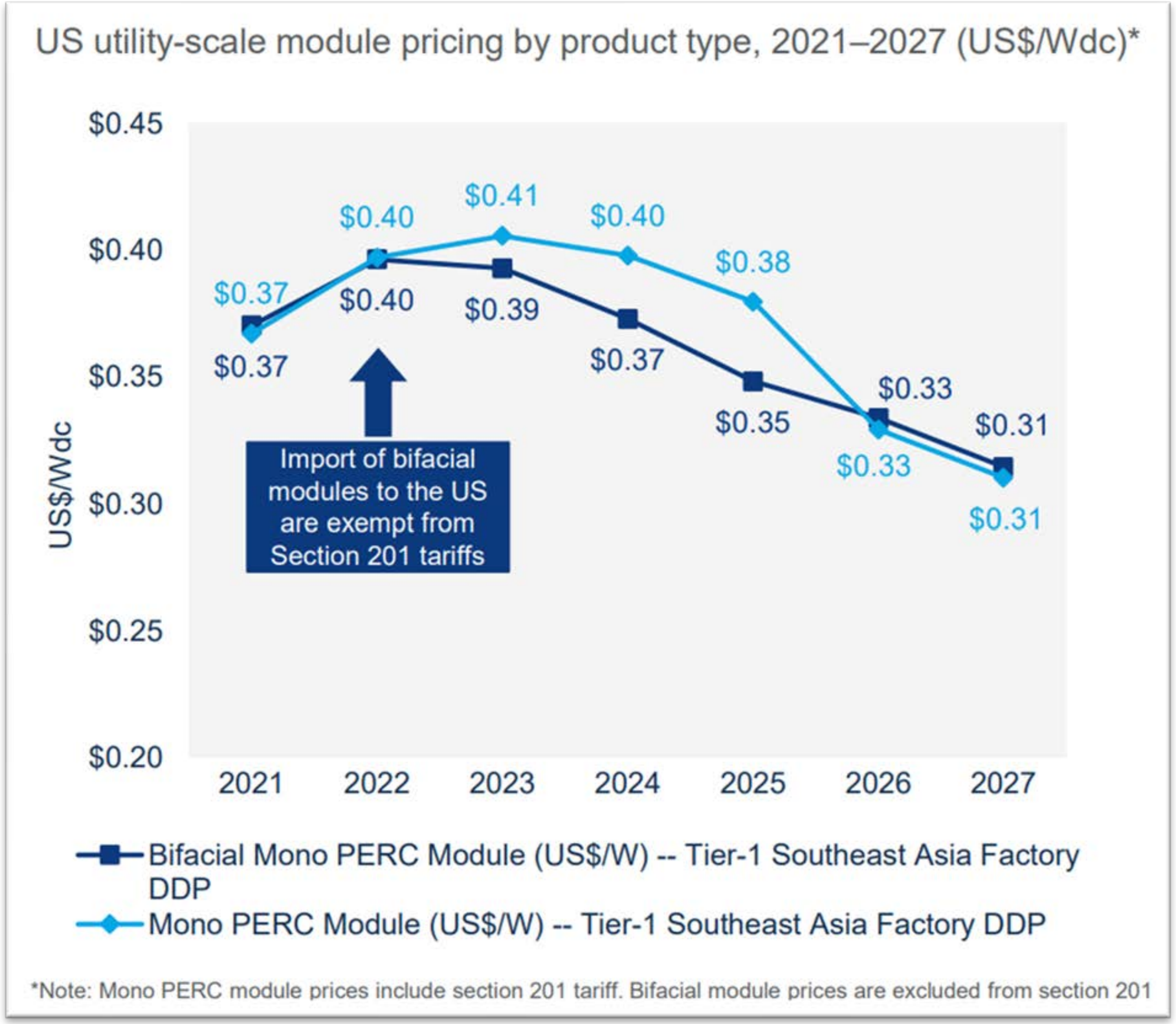
US PV Market Situation - 2021

- 2021 PV deployments of 23.6 GW_{DC}
- 46% of new US electrical capacity was PV (44% was Wind)
- Project prices increased 14% -18% year-on-year due to supply and tariff issues
- Bifacial modules remain exempt from Section 201 tariffs and are forecast to be low-cost options for any utility-scale projects that can get them.
- NREL estimates **30%-50%** of US installations in 2021 were bifacial (½ to ¾ of all utility-scale installs)



Woods Mackenzie US PV pricing forecast (March 2022)

https://www.reutersevents.com/renewables/solar-pv/us-solar-tariffs-bolster-growing-dominance-bifacial-panels

Agenda

- Bifacial field short introduction
- 3 years Technology performance comparison and degradation results
- Why and how to model bifacial fields?
  - Bifacial_radiance release and new features
  - Bifacial field modeling

75 kW Bifacial Experimental Single-Axis Tracking Field

- ❑ 5 bifacial technologies, including PERC & SHJ
- ❑ 3 Monofacial counterparts
- ❑ +8 Rear Irradiance Sensors (IMT, K&Z, Licor)
- ❑ Module and Row electrical data
- ❑ 3 Albedometers + 1 rotating albedometer
- ❑ Custom Irradiance Evaluating Module "Hydra"
- ❑ Spectral rear data (some)
- ❑ Weather and more spectral and albedo data <60 m from field from SRRL

Upcoming Summer 2022:

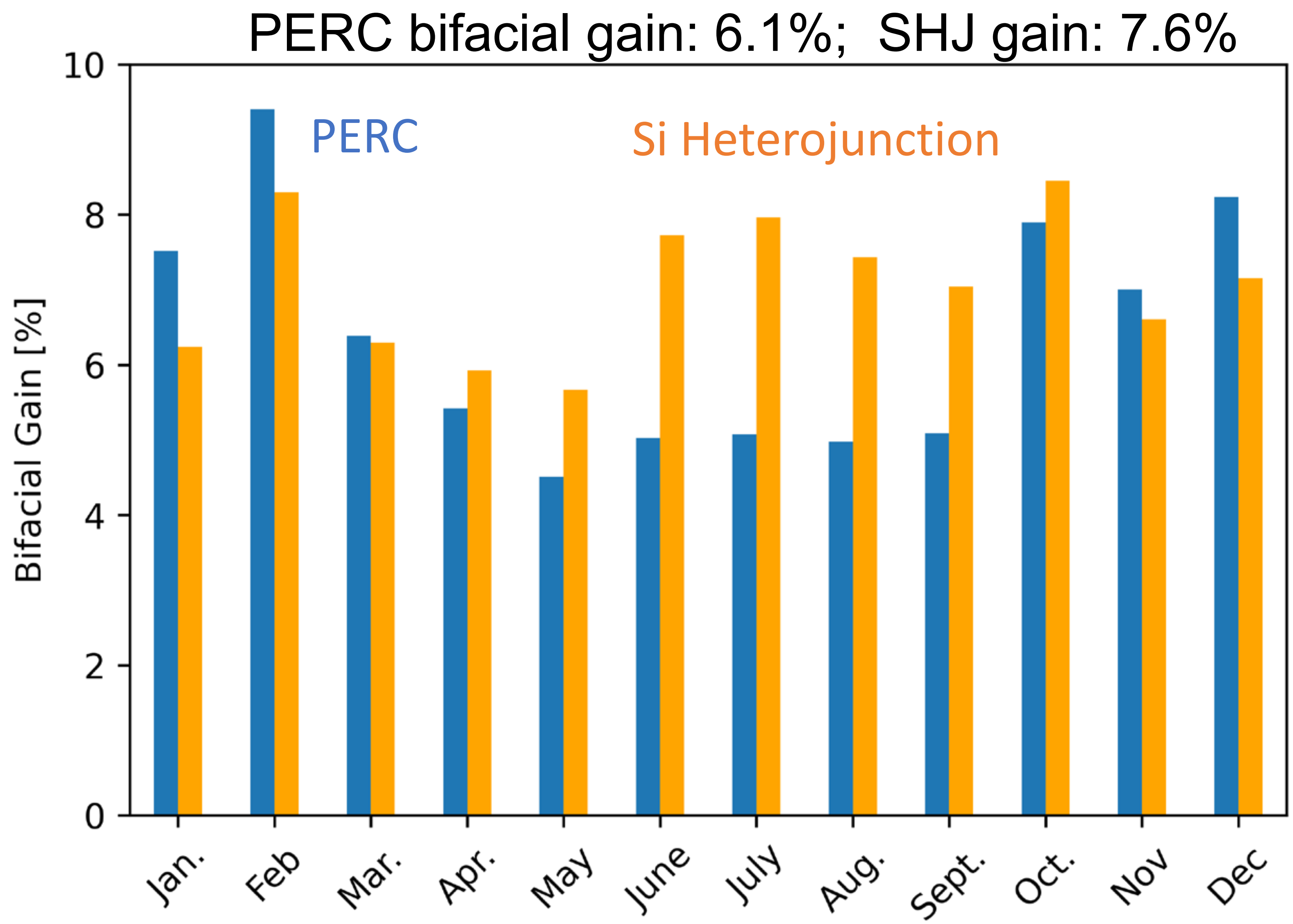
- ❑ AgriPV deployment: Pollinator Habitat, Crops & Pasture Grass
- ❑ Albedo materials testing (TBD)

Open Source on

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

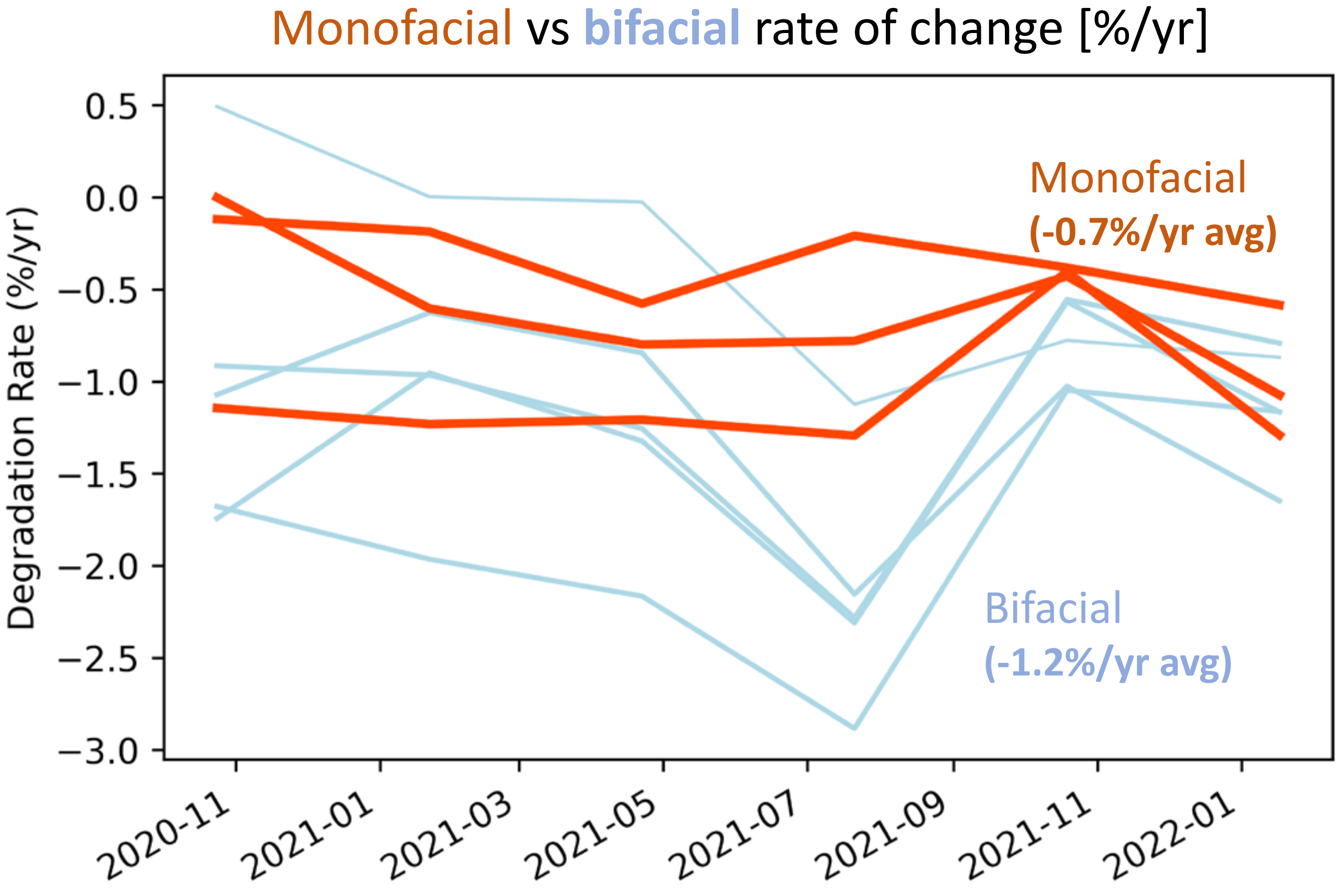
~2.5-year Technology Comparison

*Grouped by Month from Oct. 2019 to Feb. 2022



Bifacial systems can show faster initial loss

- Initial Bifacial energy gain has a slight downward trend over 2.5 years.
- On average, bifacial PERC and Si-HJT are degrading faster than monofacial counterpart



RdTools

Why and how to model bifacial fields

New system design

Hourly, typical meteorological data
Due diligence software, production and even cost models
Optimizing for terrain features, weather resiliency, yield & cost
"Danger": not taking full advantage of the bifacial advantage

Comparing for capacity testing

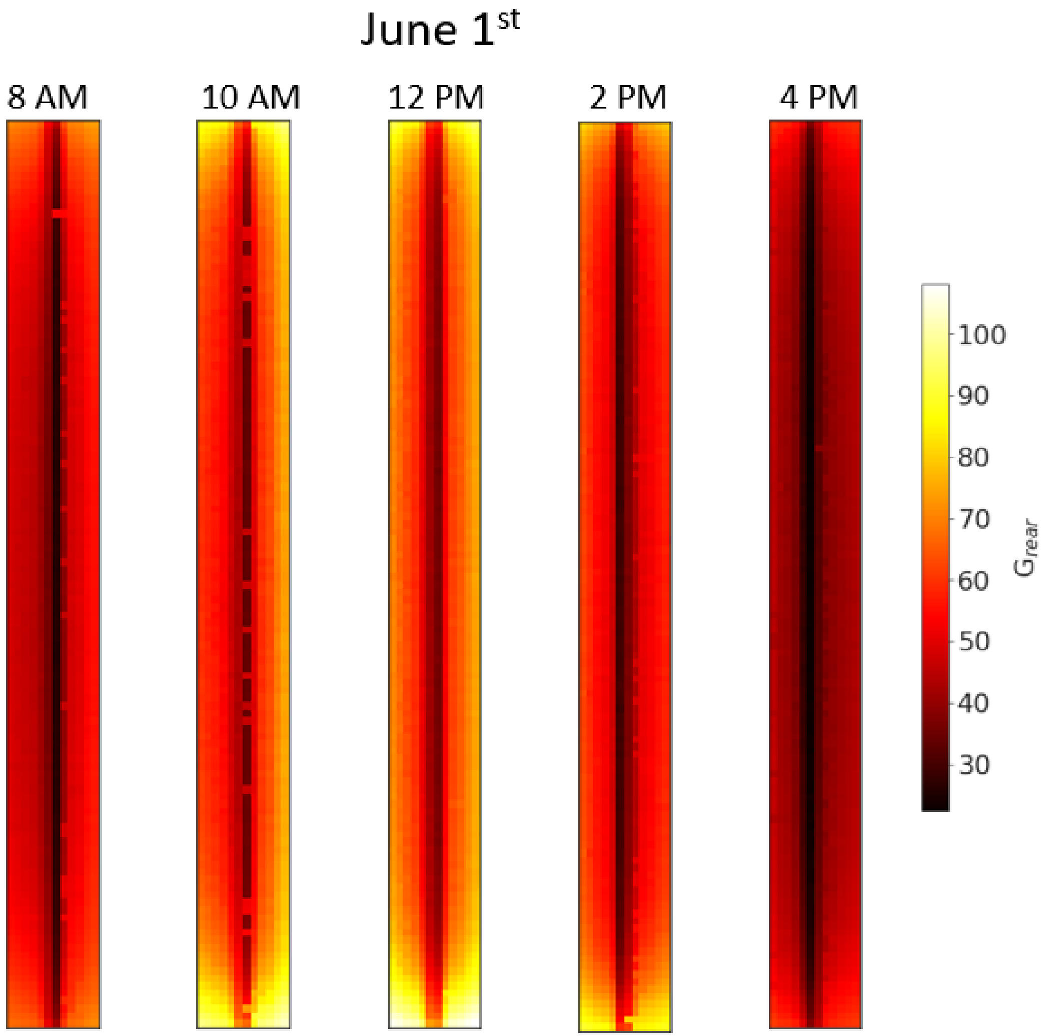
Requirement during initial powering of a system
Standards under modification IEC 61724-2 and IEC 61724-3; some options
"**Danger**": Not selecting appropriate reference conditions; measurement error due to sensor placement; edge effects, different albedo

Performance evaluation

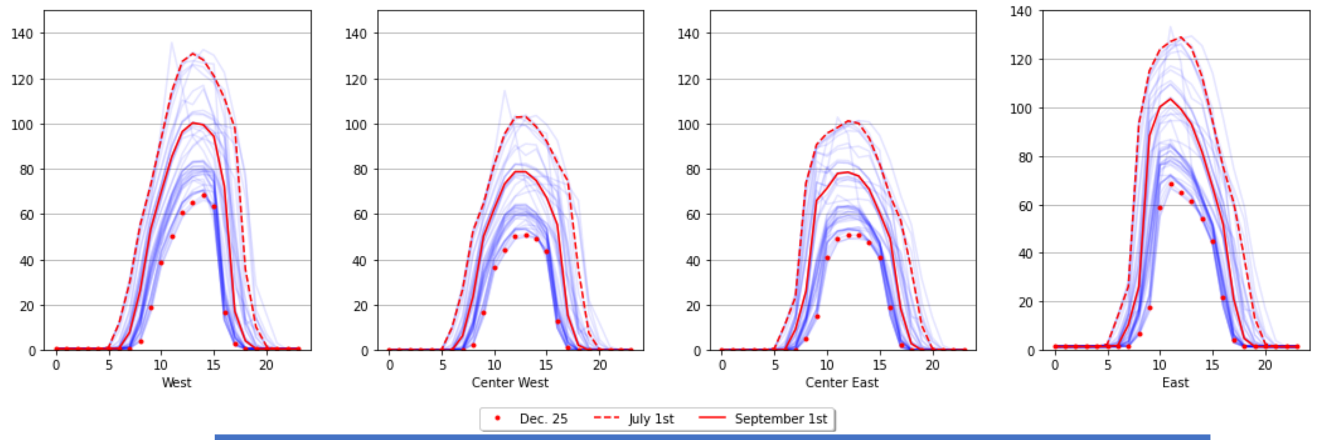
Detecting underperformance, investigate unexpected losses, planning predictive/proactive maintenance, science and knowledge gathering
"**Danger**": more than one effects causing the differences; not enough data to suss the source.

* Research

Sensor position for Capacity testing and Performance Evaluation



Clear-sky days October 2019-2021



% Difference from Reference Cell Mean

Ref. Cell (WEST)	**7**	**-12**	**-8**	**13**	**Ref Cell (EAST)**
K&Z CM11	13			30%	Licor

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

Sensor position for Capacity testing and Performance Evaluation

Custom made module “Hydra”

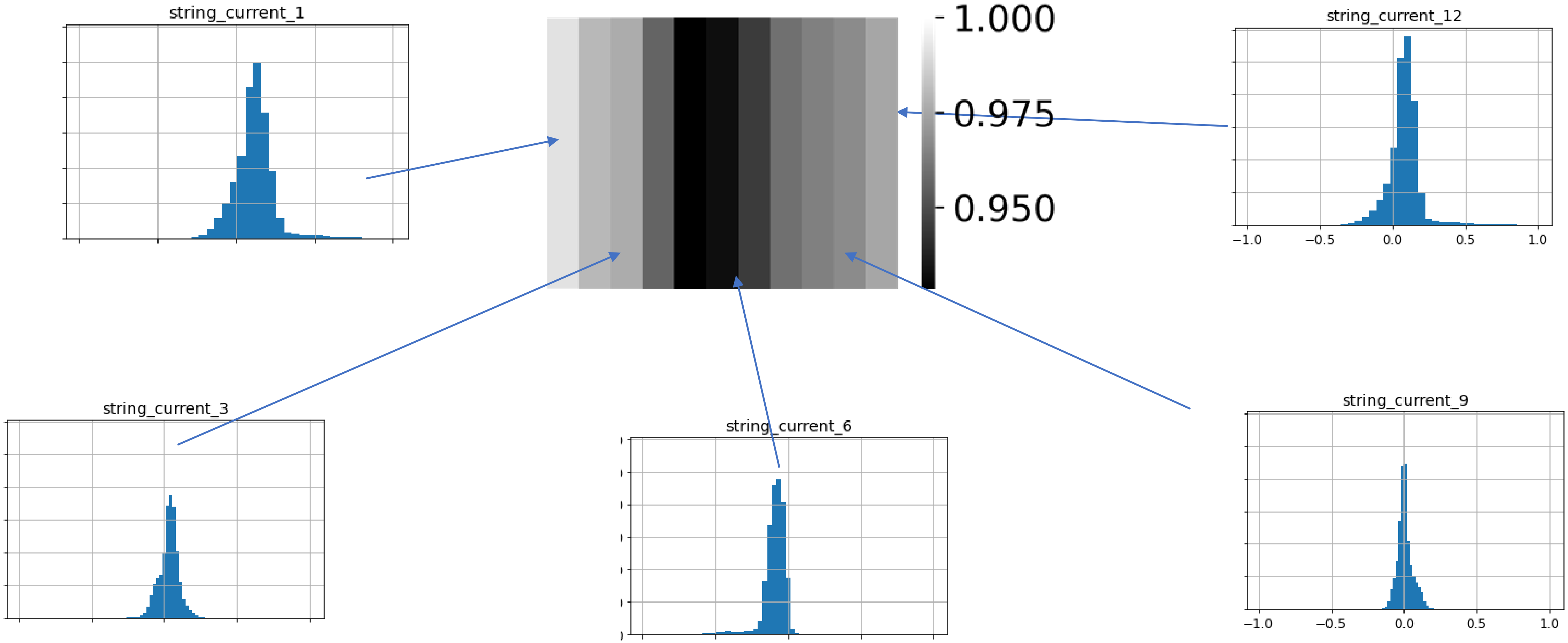
12-channels of 5 cells, Isc measurements every 3 mins.

Each channel is seeing the effects of the module rear-irradiance non-uniformity from self-shading and from torque tube

Sensor position for Capacity testing and Performance Evaluation

Normalized current across the 12 channels

Edges overpredict



Center underpredicts

Two-Sensor position for Capacity testing and Performance Evaluation

SENSOR A

SENSOR B

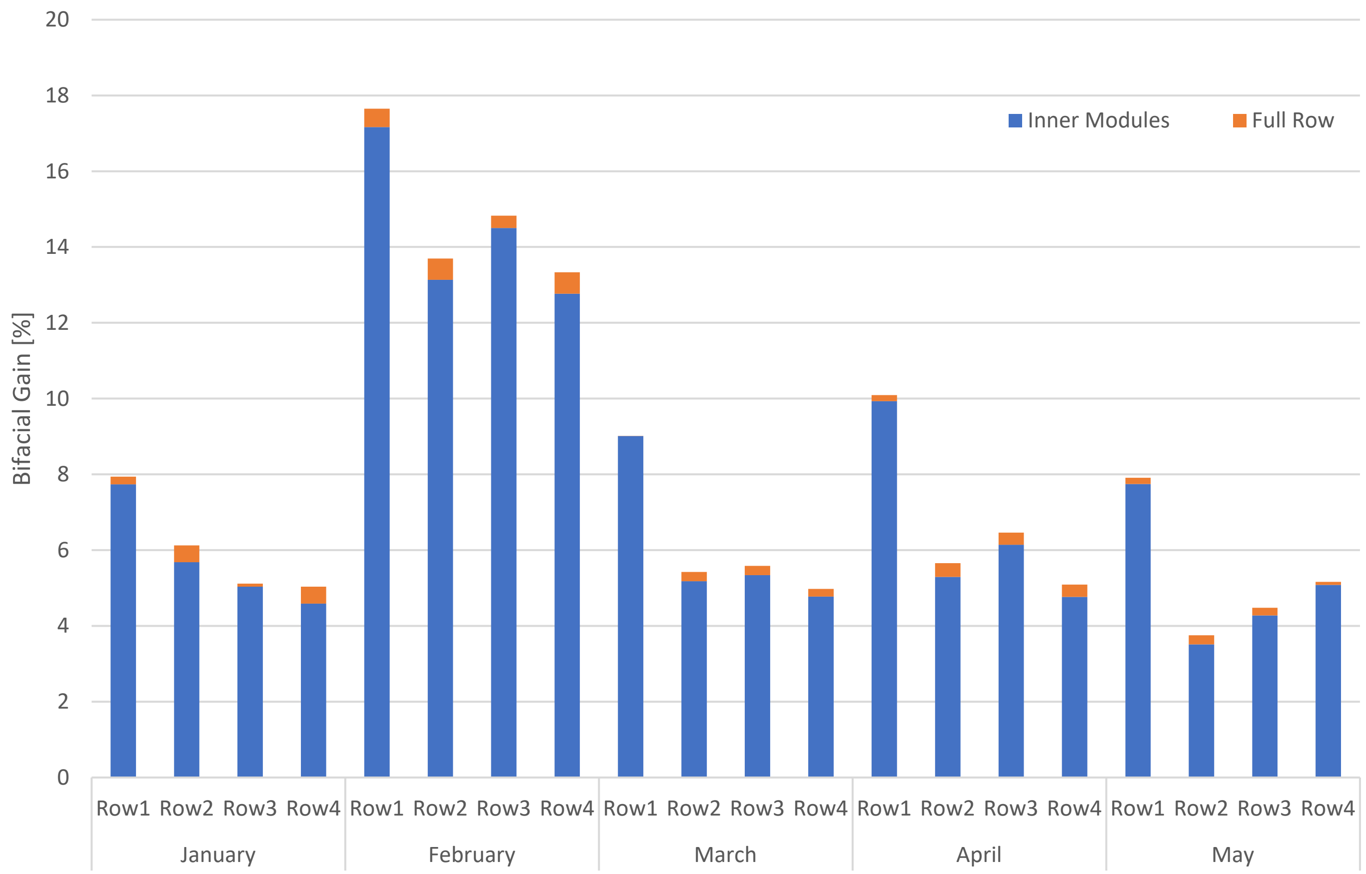
Standard Deviation from Module average

	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

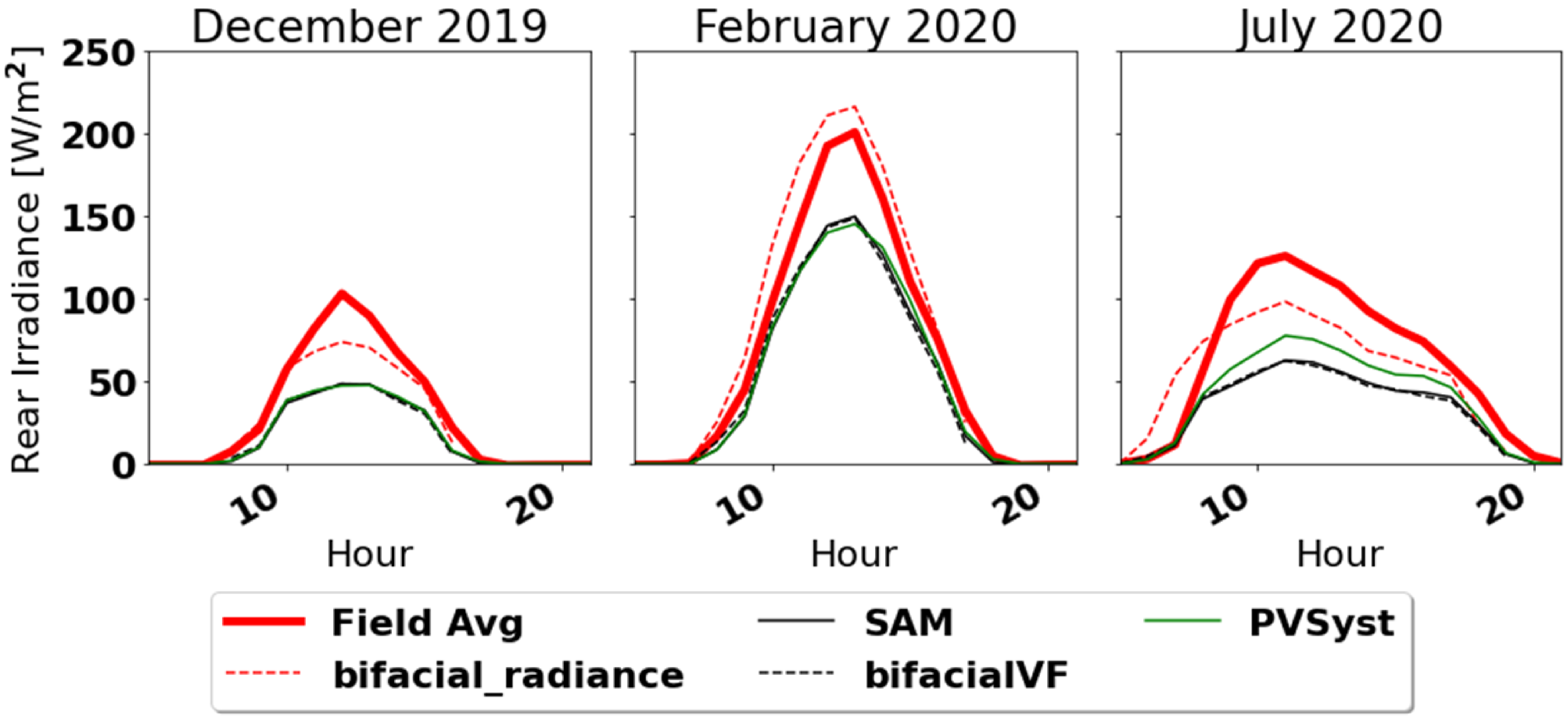
Using a combination of sensors across the module can help reduce standard deviation of the measurements

Row Edge Effects

Edge effects for five months evaluated with module-level monitoring for full row versus only inner modules show an average increase in bifacial gain of ~0.28% absolute

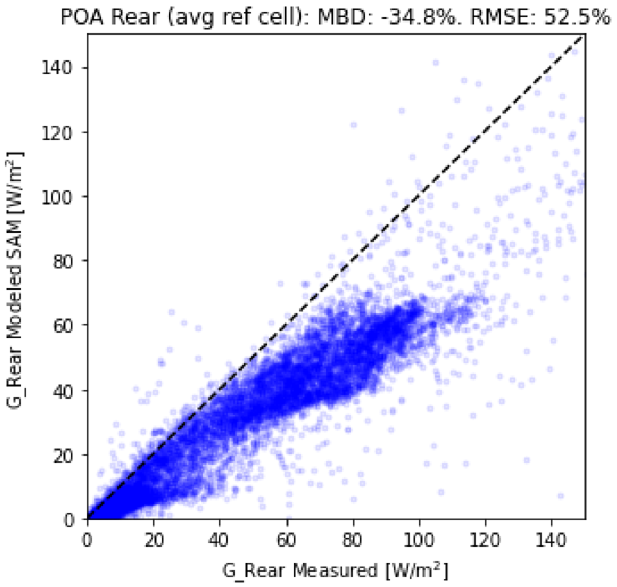


Monthly Averages: Field vs Modeled

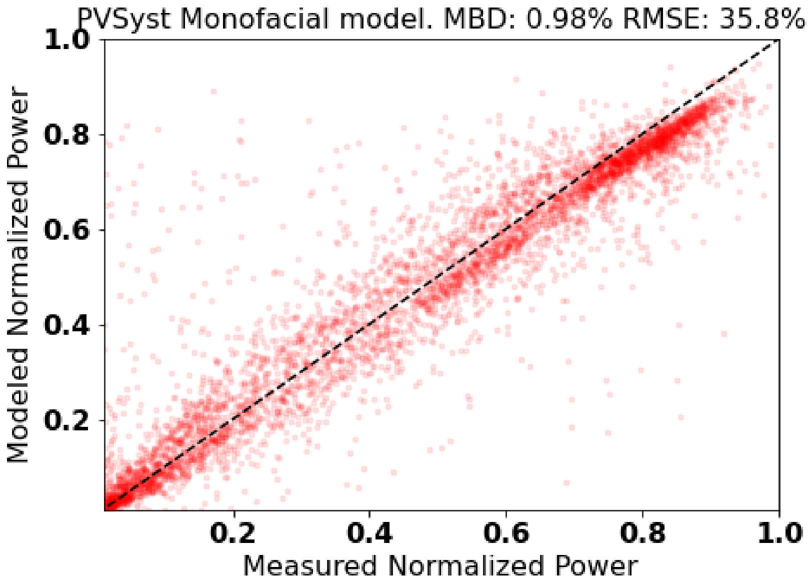


Impact of Rear Irradiance Uncertainty on Power Modeling

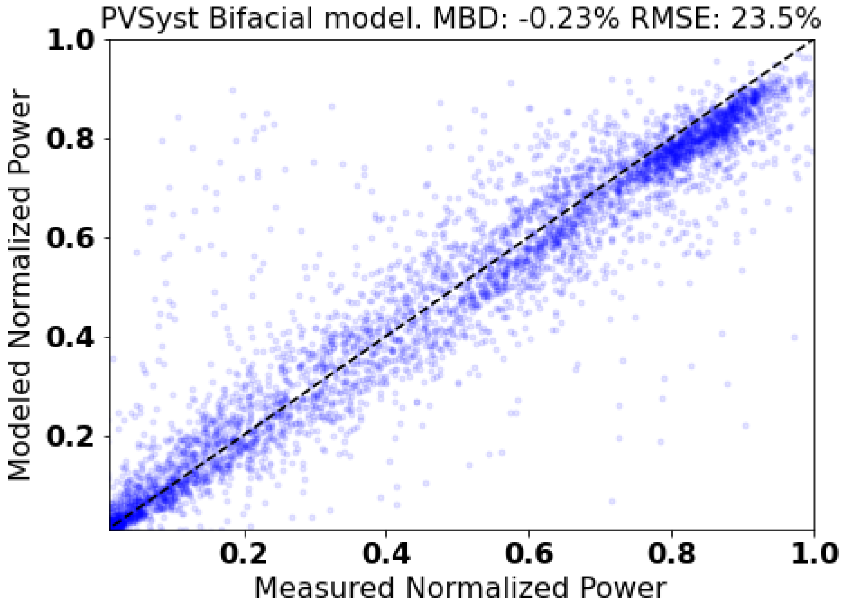
IRRADIANCE



POWER Mono



POWER BIFI



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 [2]

- bifacial_radiance
  - Routines from start-to-end weather to Performance with PVLib
    - Electrical Mismatch internal calculation with equation from [2]
  - Edge effects, electrical mismatch detailed calculation, shading routines
  - Complex model geometry: frames, omegas, glass
  - AWS Support

NREL System Advisor Model (SAM)

bifacialVF bifacial_radiance

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

Thank you

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A portion of the research was performed using computational resources sponsored by the Department of Energy's Office of Energy Efficiency and Renewable Energy and located at the National Renewable Energy Laboratory.

This work was authored [in part] by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under Solar Energy Technologies Office (SETO) Agreement Number 34910. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government.

NREL/PR-5K00-82540

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