Instrumenting bifacial fields for capacity testing and modeling

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bifiPV 2023, Dec 5 23, Doha Qatar

Why do we measure irradiance?

NREL PIX 60071

Need irradiance for plant's key performance metrics

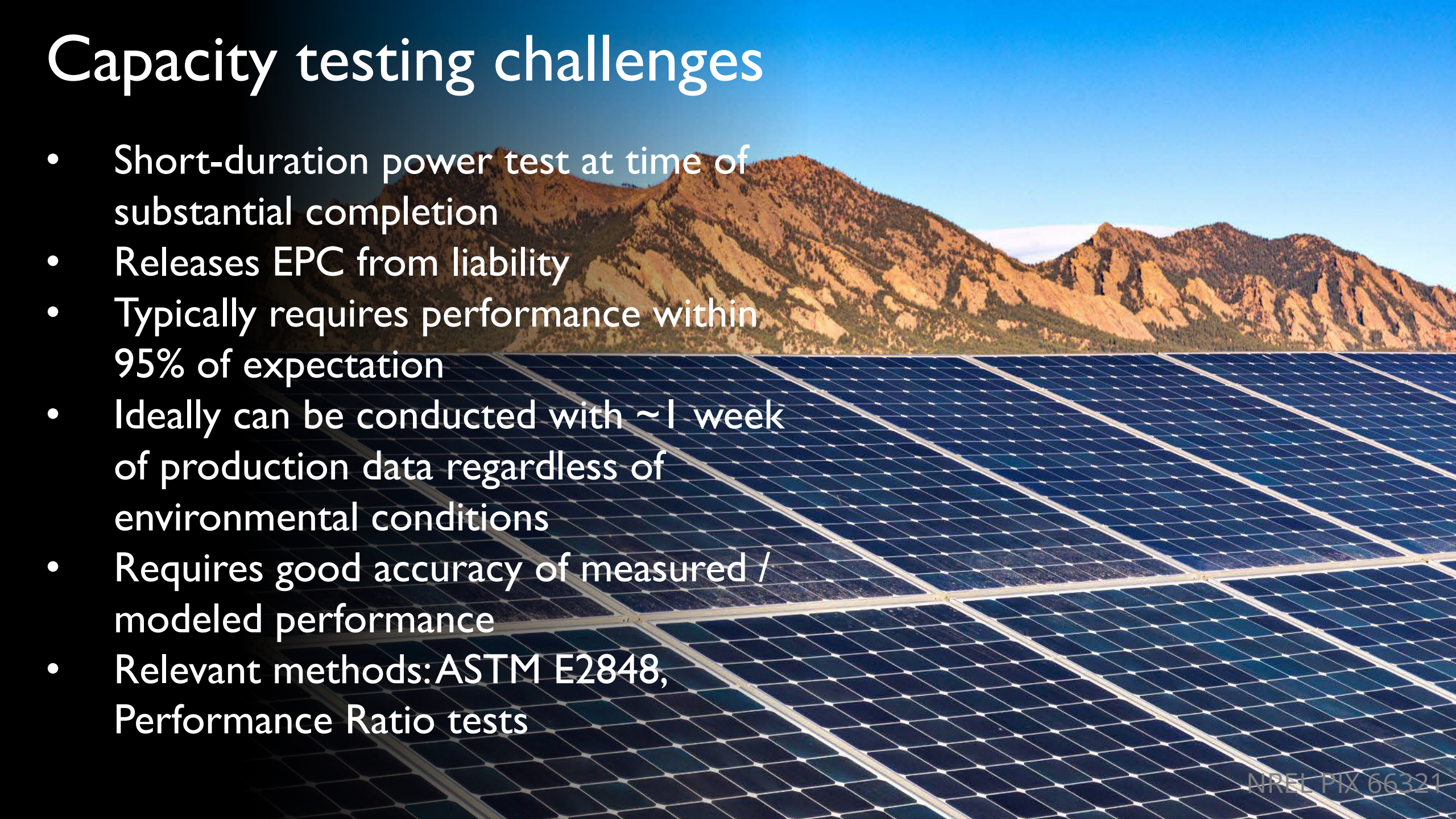
- Capacity tests
- Performance ratios
- Energy tests

$$\text{Metric} = \frac{\text{Measured Power}}{\text{Expected Power}}$$

$$\text{Expected Power} = f\,(\text{irradiance})$$

Capacity testing challenges

- Short-duration power test at time of substantial completion
- Releases EPC from liability
- Typically requires performance within 95% of expectation
- Ideally can be conducted with ~1 week of production data regardless of environmental conditions
- Requires good accuracy of measured / modeled performance
- Relevant methods: ASTM E2848, Performance Ratio tests



NREL PIX 66321

Specific challenges with bifacial irradiance

Multiple irradiance components on both front and rear POA

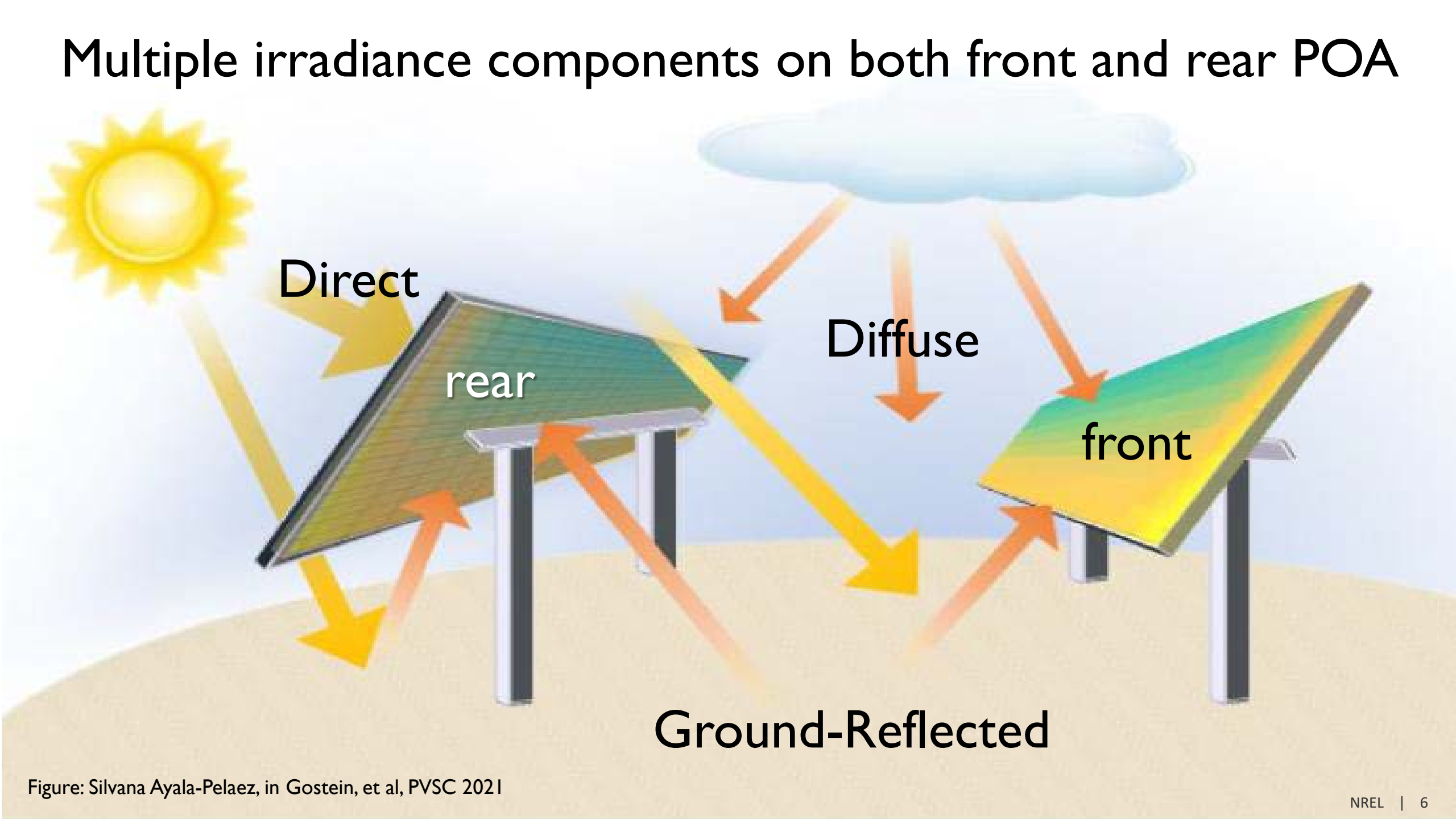


Figure: Silvana Ayala-Pelaez, in Gostein, et al, PVSC 2021

Rear-side irradiance is highly non-uniform

Rear-side irradiance is highly non-uniform

Ground albedo has seasonal variability

Industry standards for bifacial monitoring are still developing

IEC 61724-1	PV System Monitoring Instrumentation	Defines bifacial metrics and two equipment options, including measuring outside the POA (albedo) and inside (rear POA)
IEC 61724-2	Capacity Tests	*Update for bifacial in progress…*
IEC 61724-3	Energy Tests	*Update for bifacial in progress…*
ASTM E2848	Capacity Tests	Various bifacial test modifications, including substituting total front+rear POA for POA

Recommendations for monitoring rear POA irradiance

abriendomundo/Shutterstock.com

Two types of approaches for rear/total irradiance:

Measure + Model

Model rear-side irradiance based on albedo + GHI, DNI, DHI, POA

Follows model from design phase

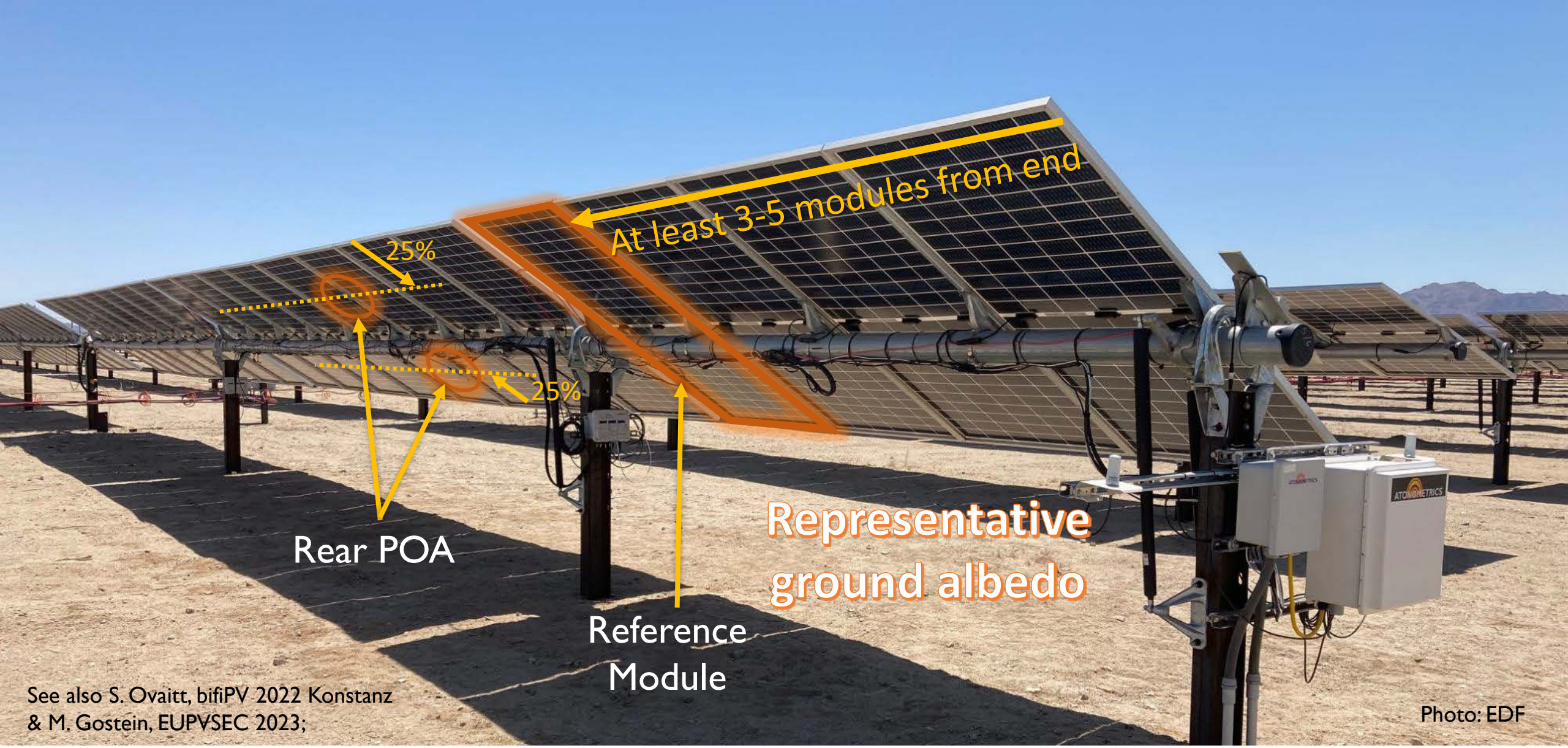
IEC 61724-1 Option 1

Measure

Directly measure rear-side irradiance with rear-side sensors or reference modules

Substitute $G_{total} = G_{front} + \phi_{bifi} * G_{rear}$

IEC 61724-1 Option 2



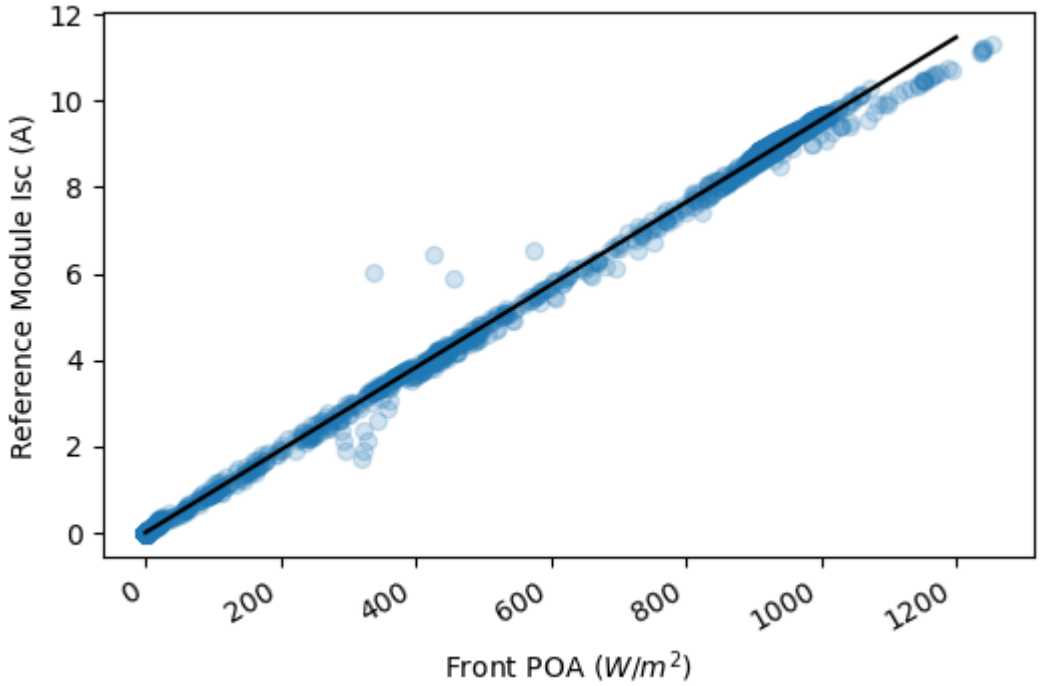
Rear-side sensor placement

NREL Bifacial Reference Module – custom design

- 12 separate bifacial channels
- Designed to measure Isc nonuniformity
- Averaging over all channels gives a more typical reference module response

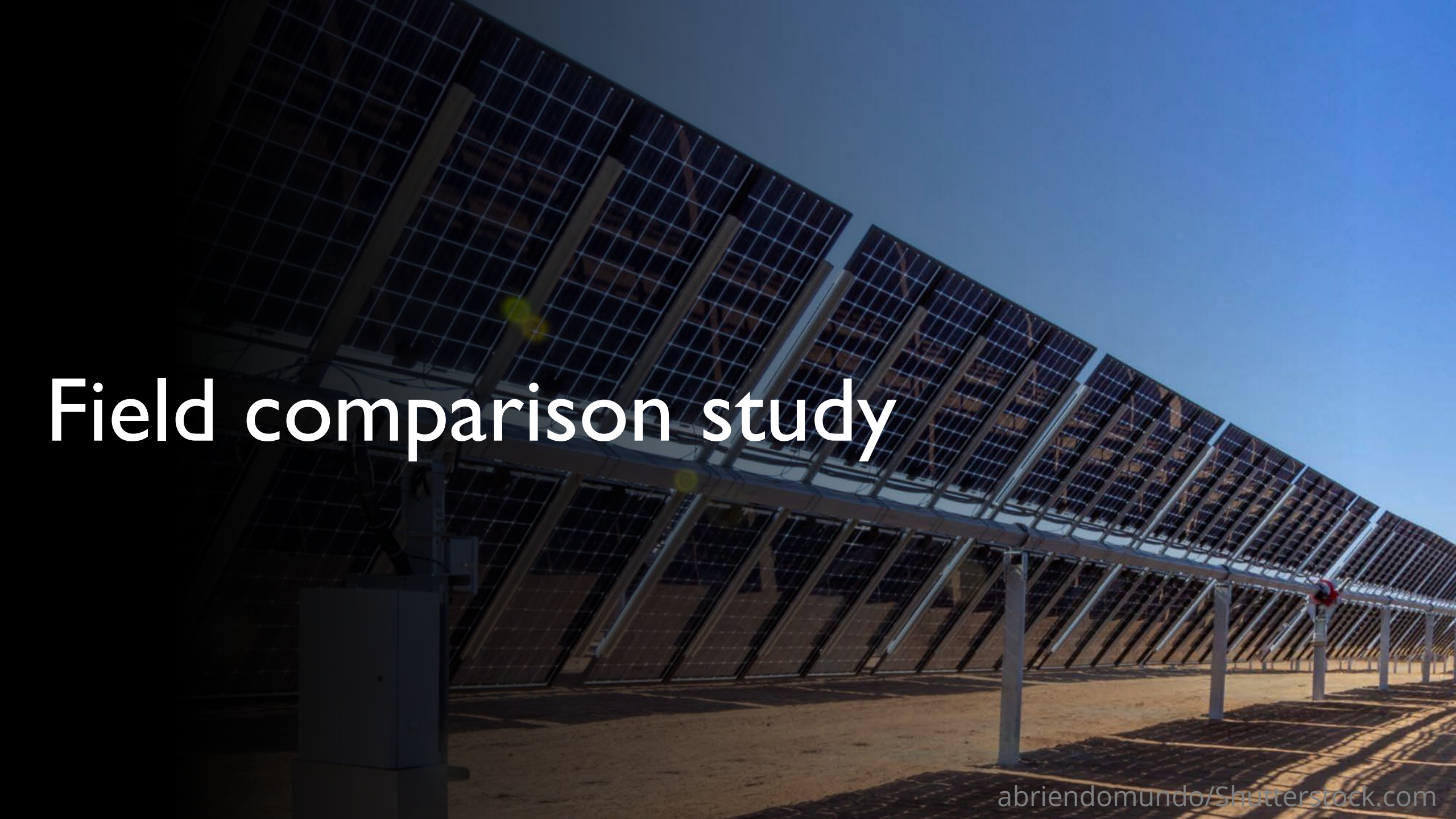
Normalized current across the 12 channels

Bifacial Reference Module field calibration



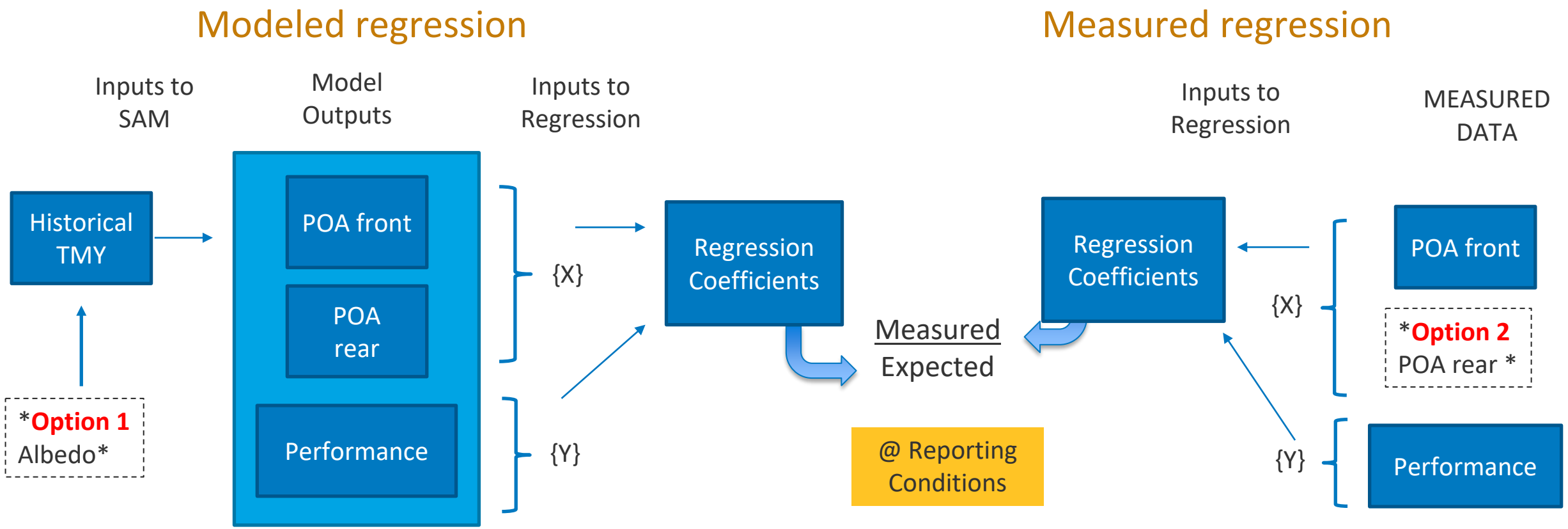
With the **rear covered**, compare front-only reference module Isc with a high-accuracy POA sensor to get a low bias calibration coefficient.

Field comparison study



Capacity test comparison

- 1 year of performance data is collected from 2 rows (15kW) of bifacial modules and 1 row of monofacial. Data is divided into 1-week segments and compared vs model (SAM).
- Follow ASTM E2848 method, which regresses Power vs POA, Tamb and Windspeed



sam.nrel.gov

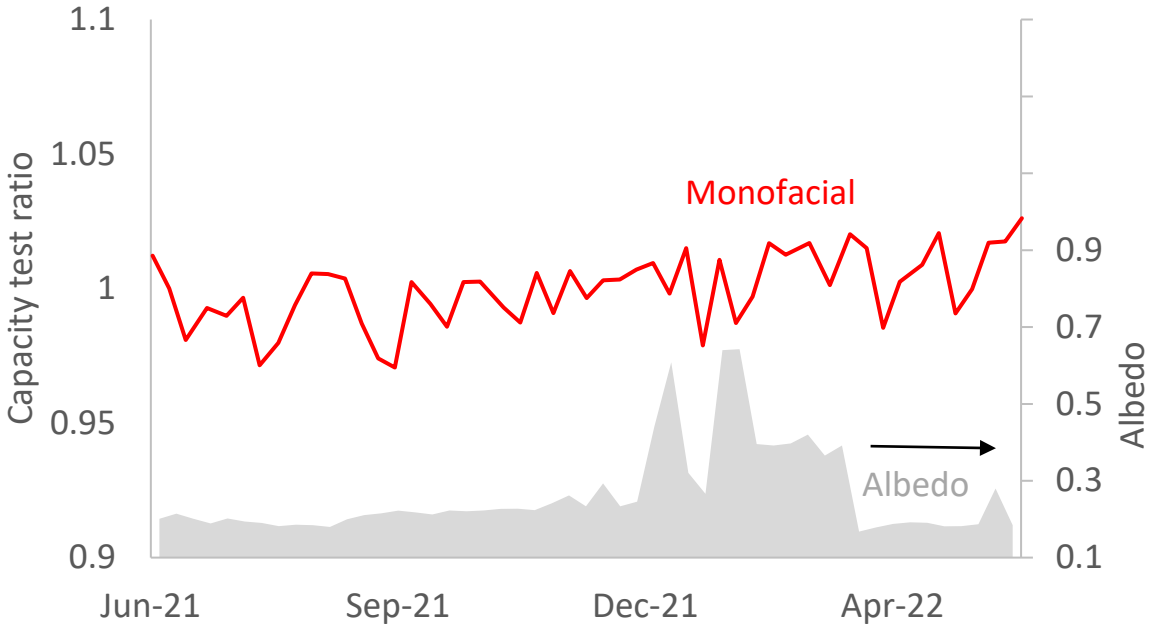
ASTM E2848 Capacity Test Regression, using IEC 61724-1 Option 1 or Option 2

Summary of configurations

- Four rear irradiance measurement options: None; albedometer; rear reference cell; bifacial reference module

Method	System	Unique Instrumentation for method	Treatment of Rear Irradiance
Baseline	Monofacial or Bifacial	• Front POA (G_{front})	N/A
Option 1 (IEC 61724-1)	Bifacial	• Albedo • DHI, GHI	Modeled from external resource measurements (DHI, GHI, Albedo)
Option 2 RefCell (IEC 61724-1)	Bifacial	• Front POA (G_{front}) • Rear POA (G_{rear}) using reference cell	Directly measured front and rear POA
Option 2 RefMod (IEC 61724-1)	Bifacial	• Total POA (G_{total}) via reference module	Directly measured total front + rear POA

Capacity test: Measured / Modeled at target conditions

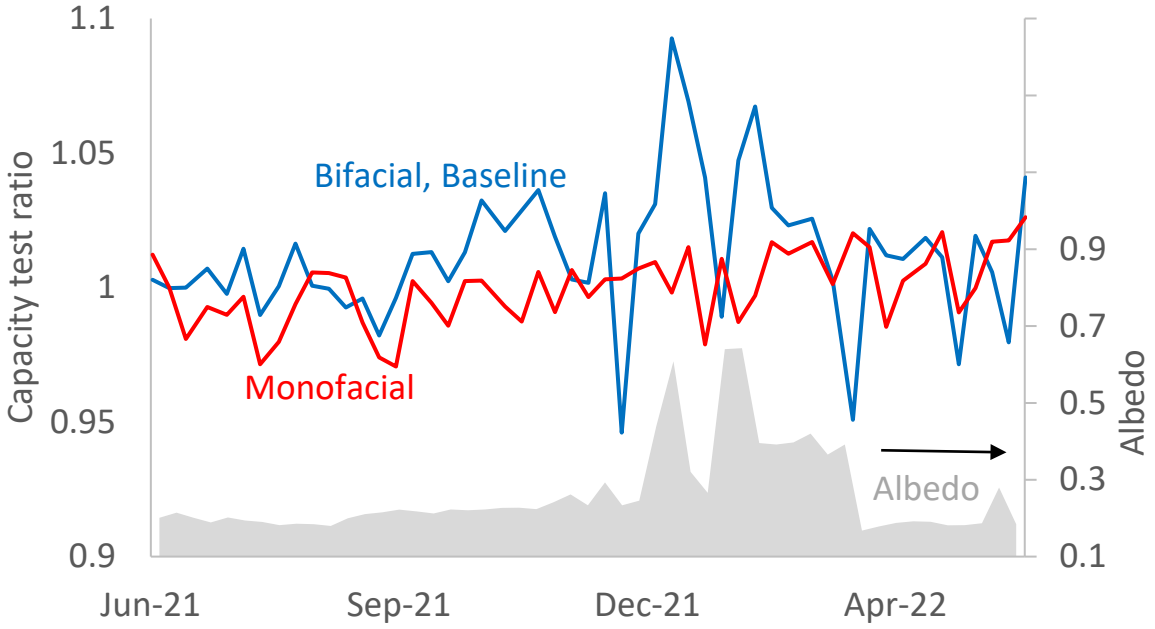


Capacity test ratio max() and min() for the year

Method	Capacity ratio (min, max)
Monofacial baseline	0.97, 1.03

Capacity test: Measured / Modeled at target conditions

Baseline conditions (front POA only)

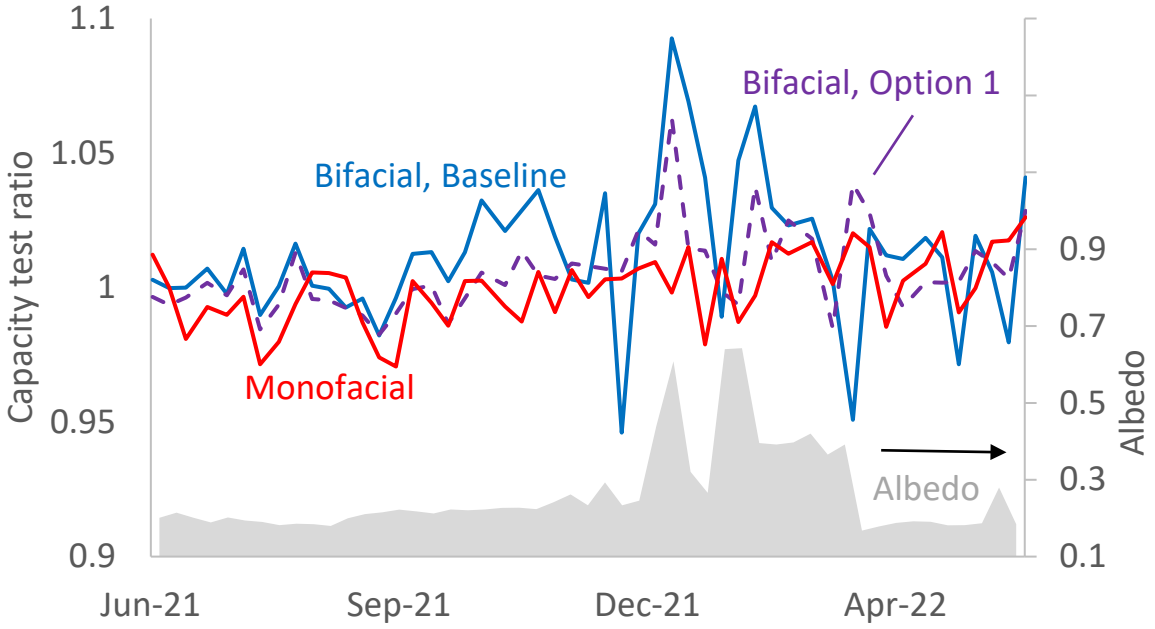


Capacity test ratio max() and min() for the year

Method	Capacity ratio (min, max)
Monofacial baseline	0.97, 1.03
Bifacial baseline	0.95, 1.09

Capacity test: Measured / Modeled at target conditions

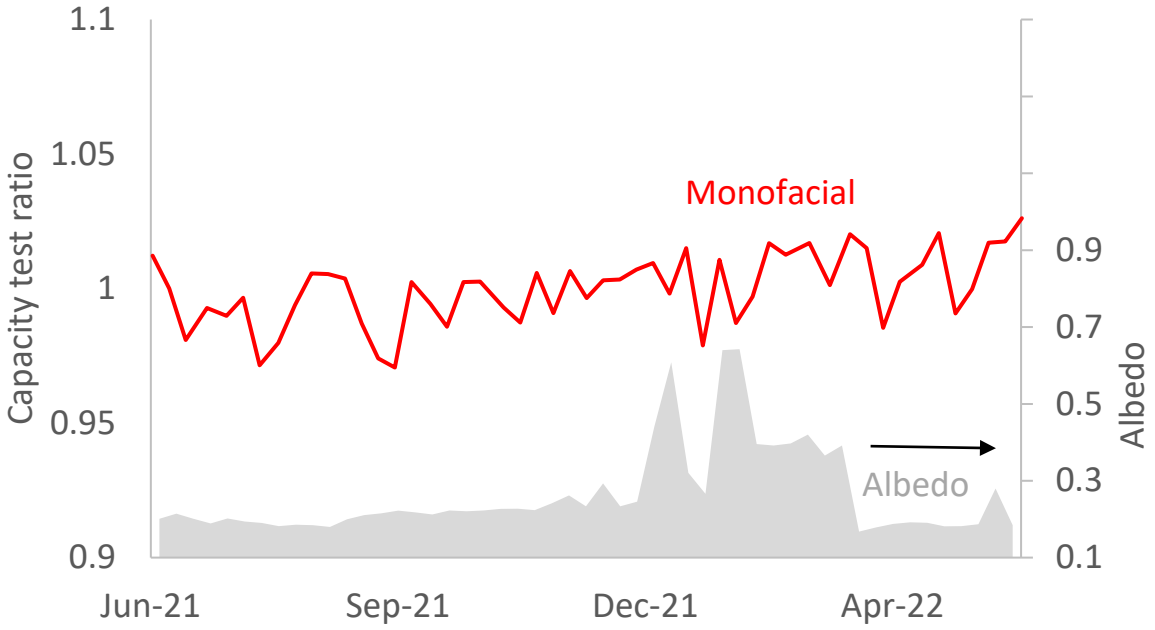
Bifacial Option 1 (albedometer)



Capacity test ratio max() and min() for the year

Method	Capacity ratio (min, max)
Monofacial baseline	0.97, 1.03
Bifacial baseline	0.95, 1.09
Bifacial Option 1	0.98, 1.06

Capacity test: Measured / Modeled at target conditions



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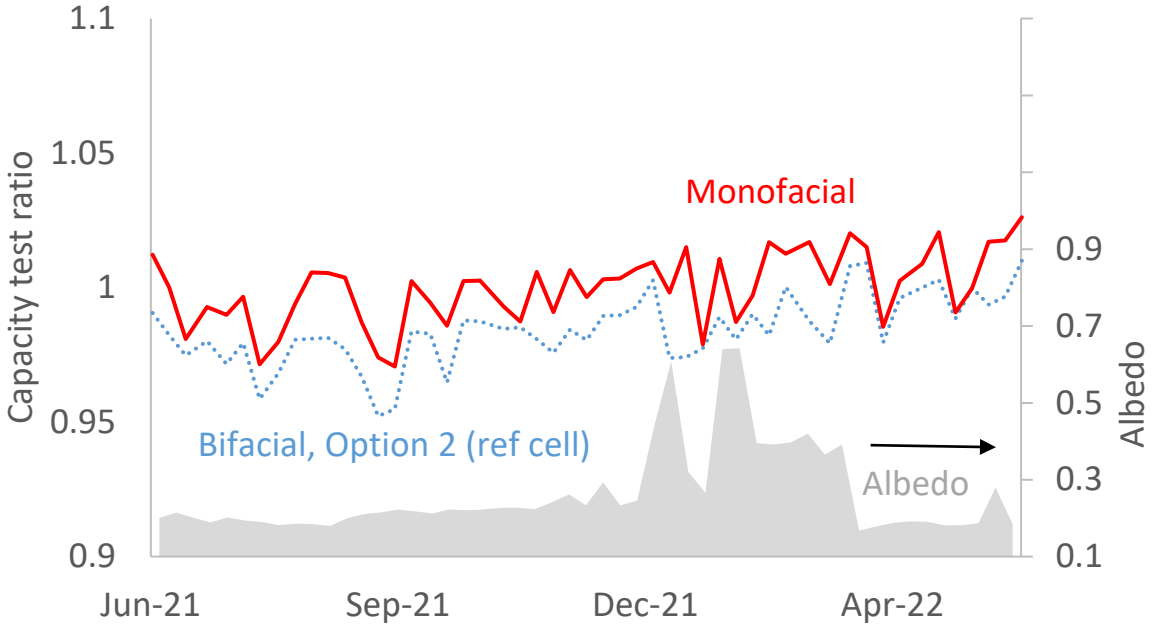
Bifacial Option 1	0.98, 1.06

Capacity test: Measured / Modeled at target conditions

Bifacial Option 2 (reference cell)

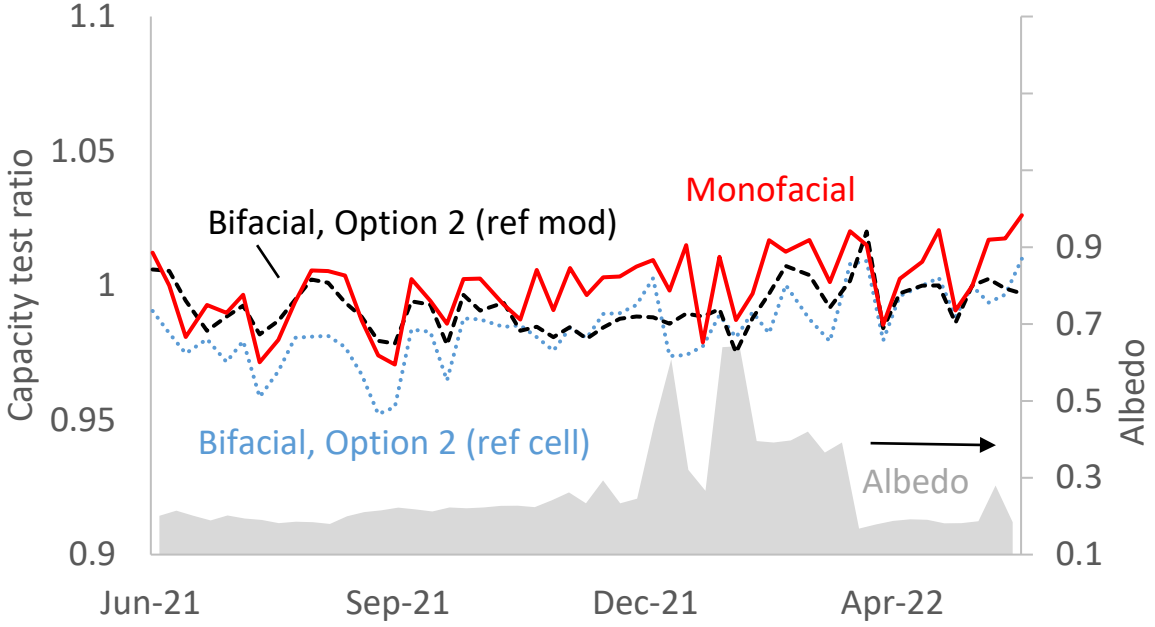


Capacity test ratio max() and min() for the year

Method	Capacity ratio (min, max)
Monofacial baseline	0.97, 1.03
Bifacial baseline	0.95, 1.09
Bifacial Option 1	0.98, 1.06
Bifacial Option 2 (ref cells)	0.95, 1.01

Capacity test: Measured / Modeled at target conditions

Bifacial Option 2 (reference module)



Capacity test ratio max() and min() for the year

Method	Capacity ratio (min, max)
Monofacial baseline	0.97, 1.03
Bifacial baseline	0.95, 1.09
Bifacial Option 1	0.98, 1.06
Bifacial Option 2 (ref cells)	0.95, 1.01
Bifacial Option 2 (ref mod)	0.98, 1.02

Conclusions

- G_{Rear} spatial variability requires careful placement of sensors
- High albedo conditions increases the variability of capacity test and performance ratio
- Following IEC 61724-1 Option 1 (albedometer and DHI measurement) enables rear irradiance to be calculated, if the original production model can still be used.
- Adding G_{rear} or G_{total} measurements with reference cells or modules reduces variability due to albedo
- Field calibration of reference cells & modules improves accuracy and reduce bias errors

Thank you

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NREL/PR-5K00-88193

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 38258.
Thank You to DOE and our PV Fleet Partners!