

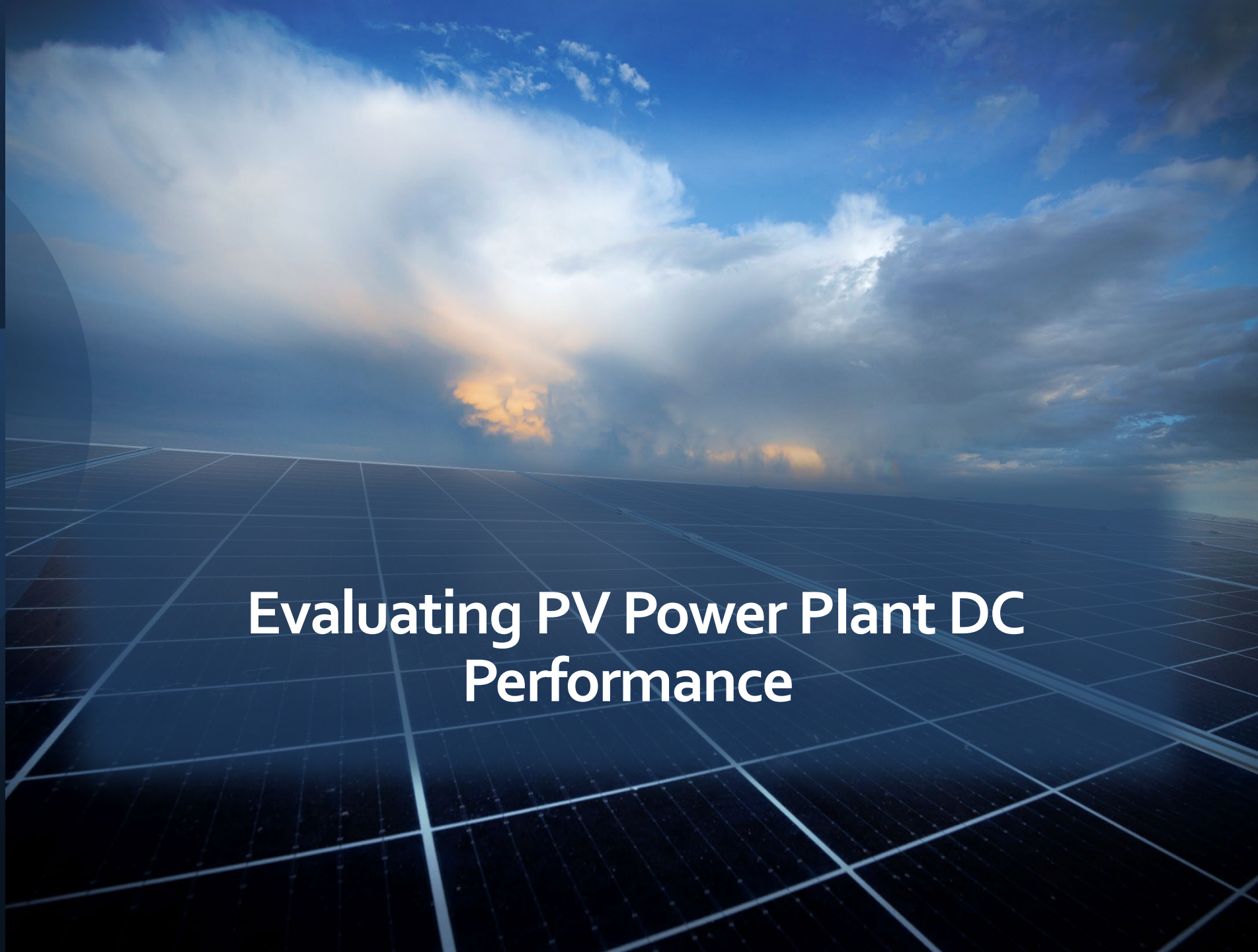
CFV Labs
Albuquerque, NM

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CEO

2024-05-07

CFV Labs

Evaluating PV Power Plant DC Performance



CFV Labs



- CFV Labs is an independent PV test and research lab in Albuquerque, NM.
- We perform performance and reliability testing on all types of PV technologies for Developers, EPCs and Manufacturers.
- We execute indoor testing in our 27,000 sq. ft. lab, outdoor testing in our test yard, and field testing at client sites.

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Introduction

- PV Power Plant Performance is affected by many factors:
 - Realized Solar Resource (Weather)
 - Tracker and Inverter Availability
 - Component Performance
 - Etc.
- Today we will talk about DC-side module performance, reasons Developers and EPCs might want to understand it better, and methods available for evaluating it.

Motivation

- We see more than a few PV projects where independent module performance evaluation has not occurred:
 - Some plants are unable to meet capacity testing thresholds, or underperform to the extent that EPCs are facing contractual obligations for liquidated damages. This creates project slowdowns.
- Why it's worth knowing how PV modules are actually performing:
 - Batch QC flash testing as part of procurement contracts can prevent adverse binning.
 - Whether testing reveals that modules are underperforming or not, it streamlines additional parts of an underperformance investigation and saves time and money.
 - Can provide a level set for EPC/Developer conversations in the case of capacity testing issues.
 - It can inform and provide leverage for future module purchasing decisions and/or project contract negotiations.

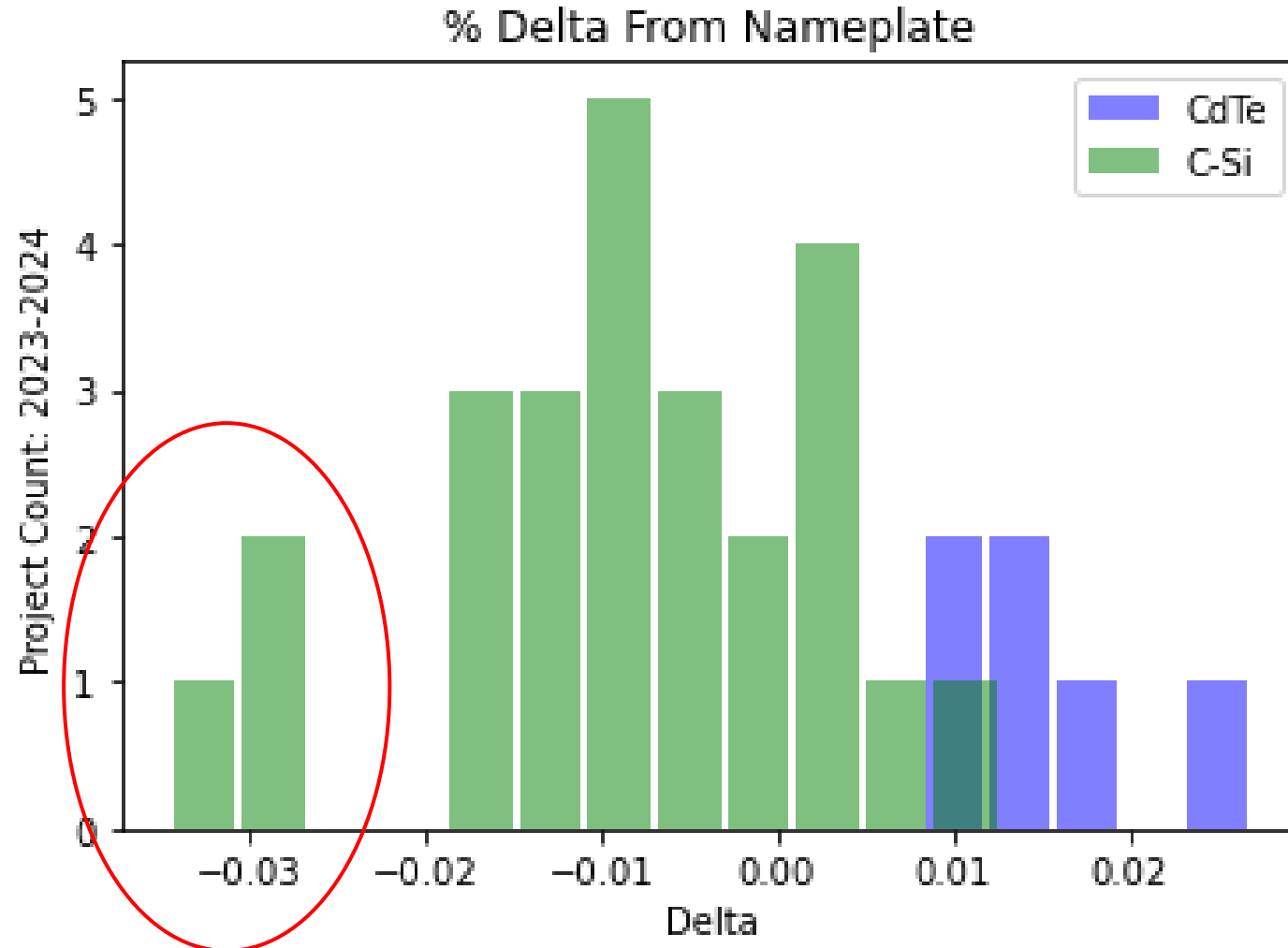
Power Plant DC Performance Measurement Strategies

- Traditional Strategies
 - Indoor Lab Flash Testing of Modules
 - Field IV Curve Tracing on-site at Power Plants
- Newer Ideas
 - “Physical Twin” installations at CFV Test Yard
 - Ongoing Remote Monitoring of PV Plant Module Reference Strings

Flash Testing:

Results from 30
QA flashing
projects at CFV
2023-2024

- Mean and median for c-Si ~1.0% below nameplate.
- Some outliers – 3 projects ~ 3.0% below nameplate
- CdTe modules flash above nameplate with chamber pre-conditioning.



Flash Testing:

h.a.l.m. A+/A+/A+
flasher

Temperature and
Irradiance Matrices
→ PAN Files

2.5m x 1.3m
capacity

250V, 25A capacity

Sectional IV for N-
Type modules

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Flash testing at CFV is used for PAN file generation, QA batch testing during procurement, and for evaluating modules shipped back from field.



Flash Testing:

A+ Spectrum

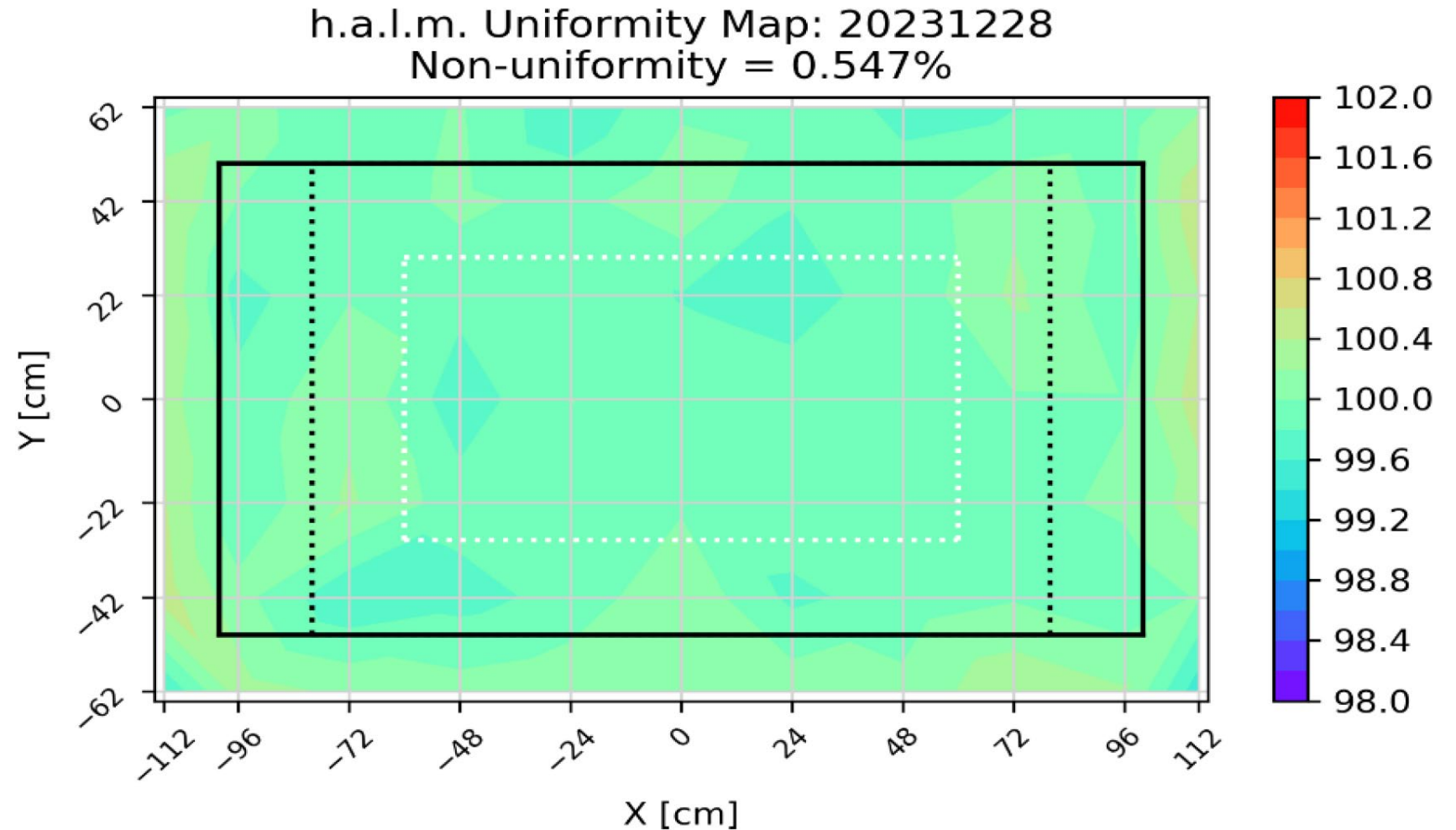
A+ Uniformity

A+ Stability

All monitored by
CFV Labs Flasher
QA Program

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Running a world class flasher program involves
multiple types of flasher QA testing in the lab at
CFV



Round Robins and Control Modules are independent checks of accurate flash measurement

Intra-lab flash testing comparisons are key to maintaining confidence in flashing programs. Here we have results from a recent comparison of CFV to Fraunhofer ISE flash results. We also have done similar comparisons with SERIS, NREL, and Sandia.

Module ID	Cell Technology	Last CFV Measurement Date	Last CFV Measured Pmp [W]	Last Fraunhofer ISE Measured Pmp [W]	Difference (CFV/Fraunhofer) – 1
CFV009	Mono PERC	2022-12-06	260.68	261.20	-0.12%
CFV010	n-PERT	2022-12-06	303.18	301.74	+0.60%
CFV012	IBC	2022-12-06	316.87	315.34	+0.55%
CFV013	Poly Al-BSF	2022-12-06	280.53	281.90	-0.42%
CFV014	CdTe	2022-12-07	109.95	109.78	+0.11%
Average					+0.15%

Understanding
flash
uncertainties is
key to
interpreting
measurement
results

CFV's STC I-V Measurement Uncertainties (k=2)

Cell Technology	Isc [A]	Voc [V]	Imp [A]	Vmp [V]	Pmp [W]
Crystalline Silicon, Monofacial	± 1.4 %	± 0.7 %	± 1.6 %	± 1.2 %	± 1.9 %
Crystalline Silicon, Bifacial	± 1.6 %	± 0.75 %	± 1.8 %	± 1.3 %	± 2.2 %
CdTe	± 2.7 %	± 1.6 %	± 2.7 %	± 2.0 %	± 3.3 %

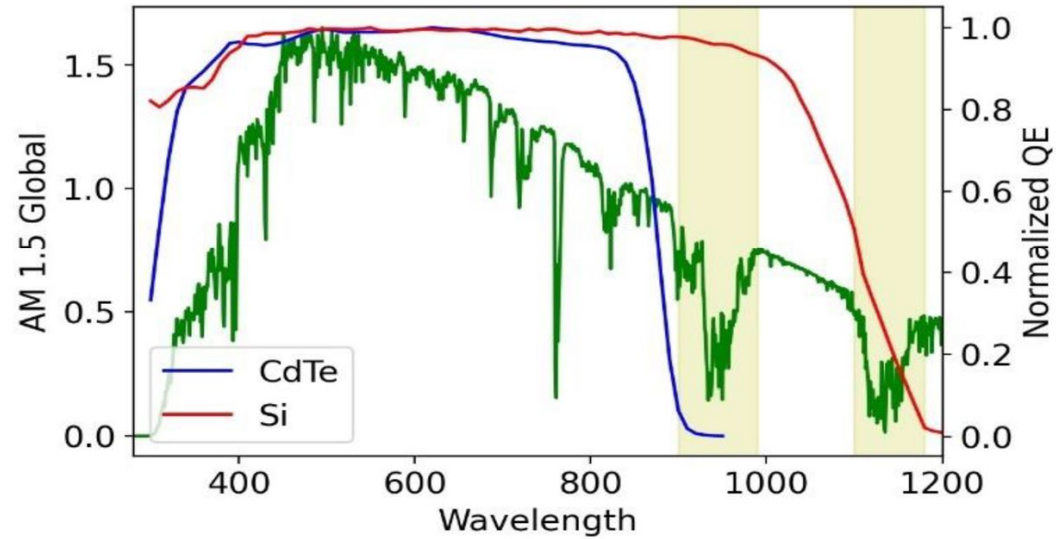
CdTe Flashing:

Requires spectral corrections to compare results with a c-Si reference cell

CdTe modules use a chamber preconditioning protocol to bring modules to a high performance state

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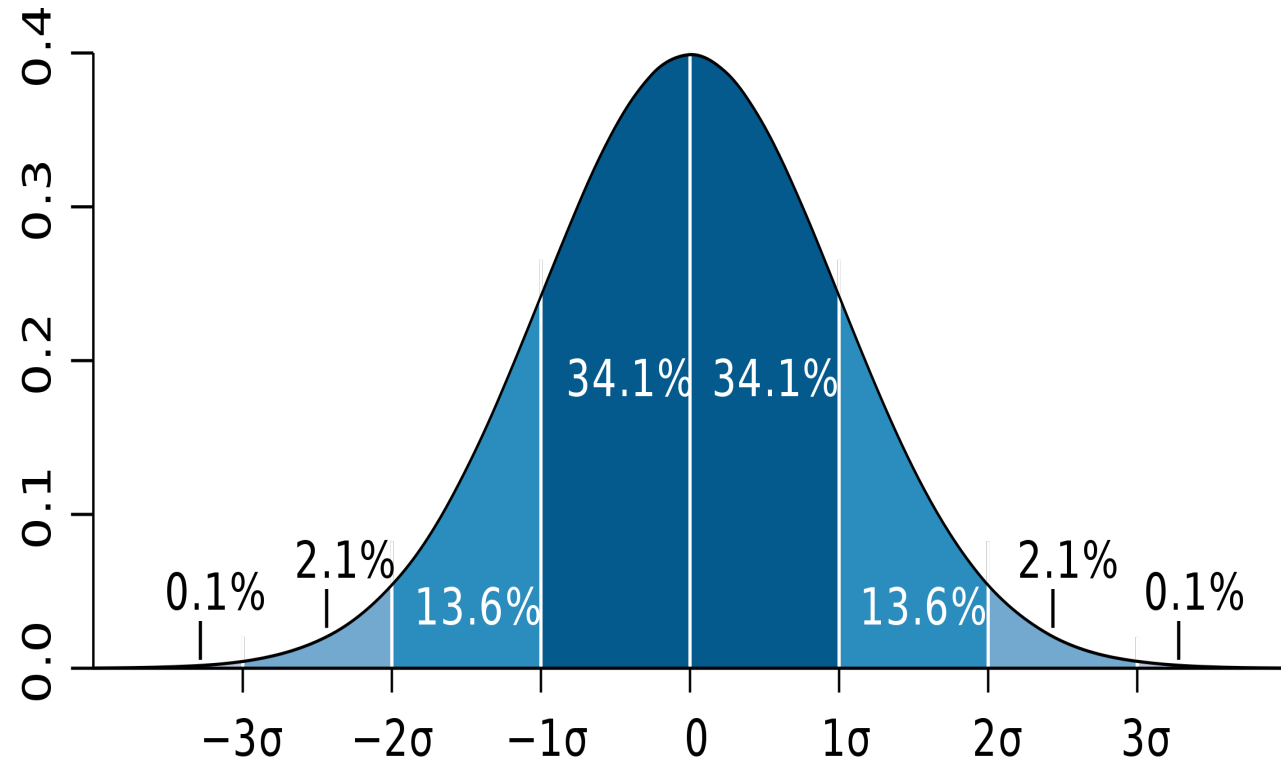
CdTe is Different – Requires Special Handling and Expertise



Sampling Sizes

If only interested in the mean, sample sizes from uniform populations don't need to be very large

For modules that display a normal "bell-curve" distribution of a parameter of interest – like STC power – we don't need a very large sample to get a good estimate of the mean, since when we choose samples they are much more likely to be in the center of the distribution:



What sampling errors do we get for typical PV modules?

- Mean estimation errors drop with increased sample size past 40, but slowly. Here we assume a standard deviation of module power of 2%, which is typical.

Measured Mean (w)	Sample Size	95% Confidence (w)	95% Confidence (%)
450	20	[446,454]	+/- .88%
450	40	[447,453]	+/- .62%
450	80	[448,452]	+/- .44%
450	160	[449,451]	+/- .31%

- These errors also need to be evaluated against the flash testing errors for PV modules which are typically around +/-2.0%-3.0%, measured in the same 95% confidence interval.

What determines a uniform sample for PV modules?

- Samples need to come from relatively uniform populations for these statistical approaches to make sense. For PV modules, especially for large projects, we will want to consider these population variants when developing a sampling plan:
 - Module Manufacturer
 - Module Model Number (not power bin)
 - Module BOM – especially cell type or cell manufacturer.
 - Module Factory
 - Module Production Dates / Serial Numbers
 - Module Power Bin
- Note: the variation in the mean of these populations is clearly not completely statistically independent.

What is a practical approach for a PV module QA sampling and testing plan?

- Determine the specific goals of the plan:
 - Mean Power Estimation
 - Defect Frequency Analysis
- Identify the number of different module populations.
- Determine sample sizes for each independent population, and randomly sample from those populations.
- In the case of ongoing production for a power plant project, ship modules as they are delivered to the site in original factory packaging to the test lab.
- Modules can be randomly sampled from individual pallets at the lab. Not every module needs to be tested from every pallet.
- Budget will frequently drive final decision making.

- Field IV advantages: on-site, on-tracker, realistic conditions, no module removal.
- Field IV disadvantages: higher uncertainties, weather risk, logistics.

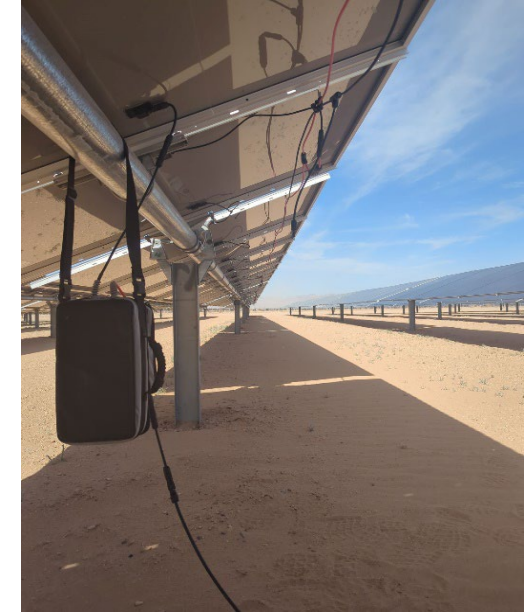
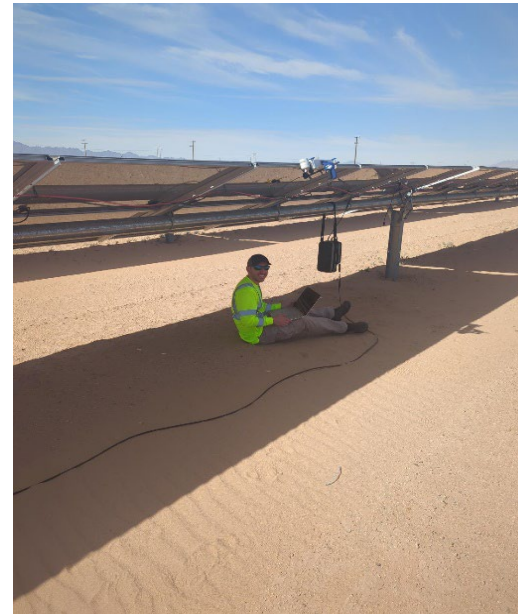
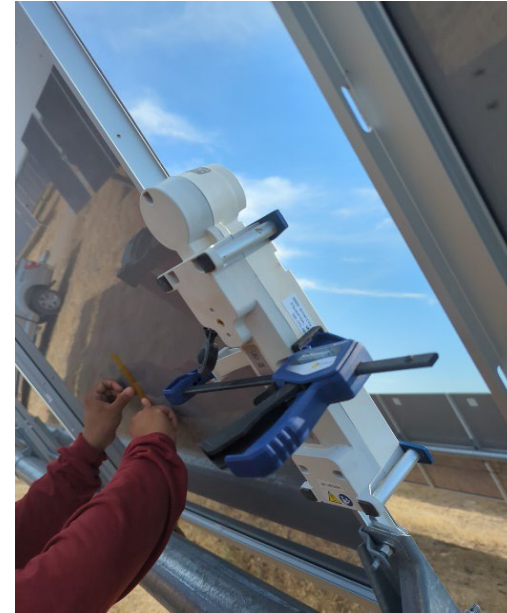
Field IV:

String level at
combiner
box



Field IV: Individual modules and sub-arrays.

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Field Soiling Measurement

IV/Clean/IV

Comparison to
Soiling Stations

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Other inspections can be done in the field as part of an IV test visit – thermal imaging, backsheet and connector inspections, etc.

**Additional
Inspections
can be done
as part of a
field visit**



**“Physical
Twin”**

**DC
Performance
Validation**

- CFV is fielding modules from PV plants currently in the construction or commissioning phase and measuring performance on Array Technologies SAT in the CFV test yard.
- This provides an independent check of module performance under realistic operating conditions and can aid in underperformance diagnoses.
- Modules are fielded in small arrays.

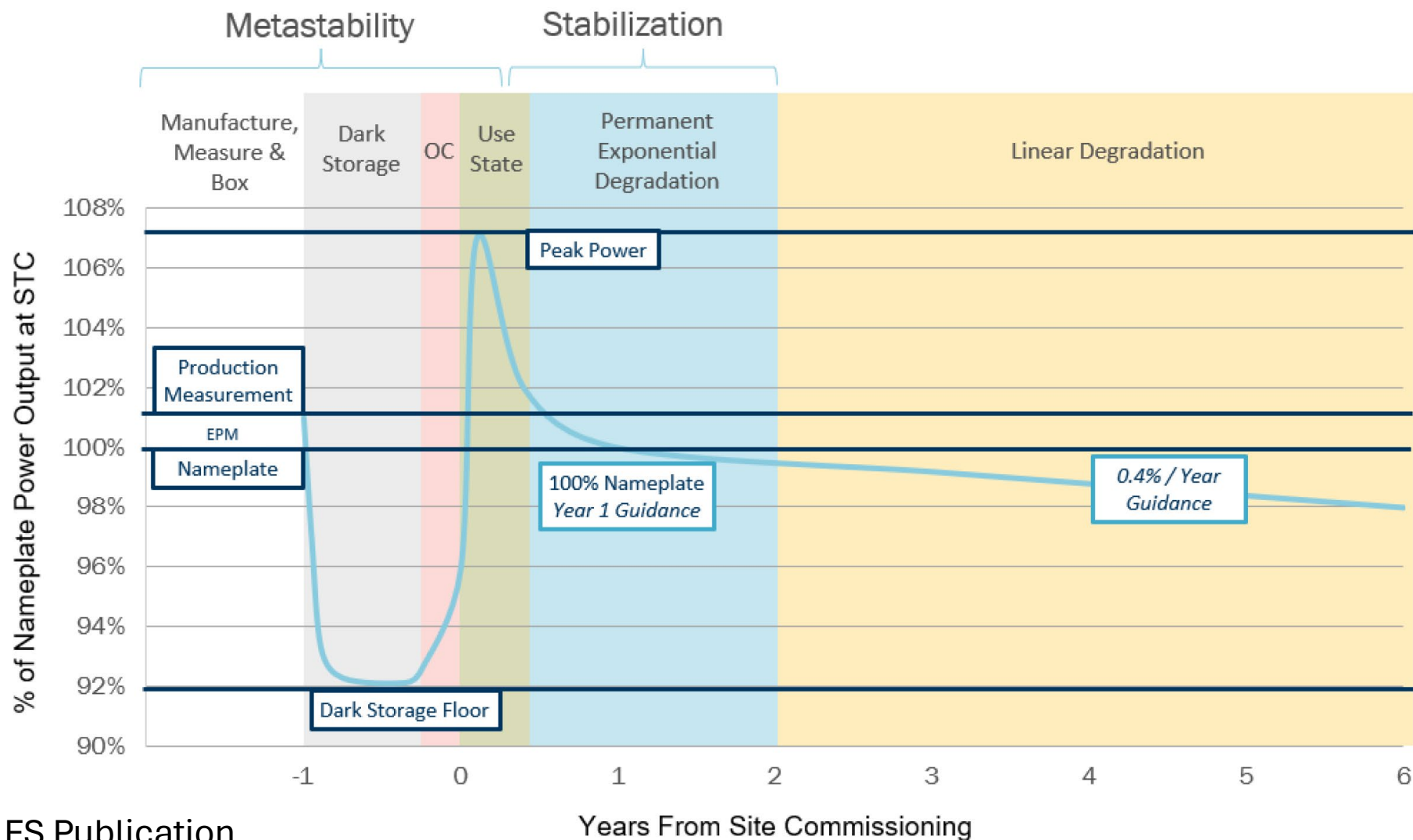


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“Physical Twin” – CdTe:

Can
independently
track
metastability or
“wake-up”
during
construction or
capacity testing
phase

One application of the Physical Twin concept is to track the timing and magnitude of CdTe Metastability and Stabilization.



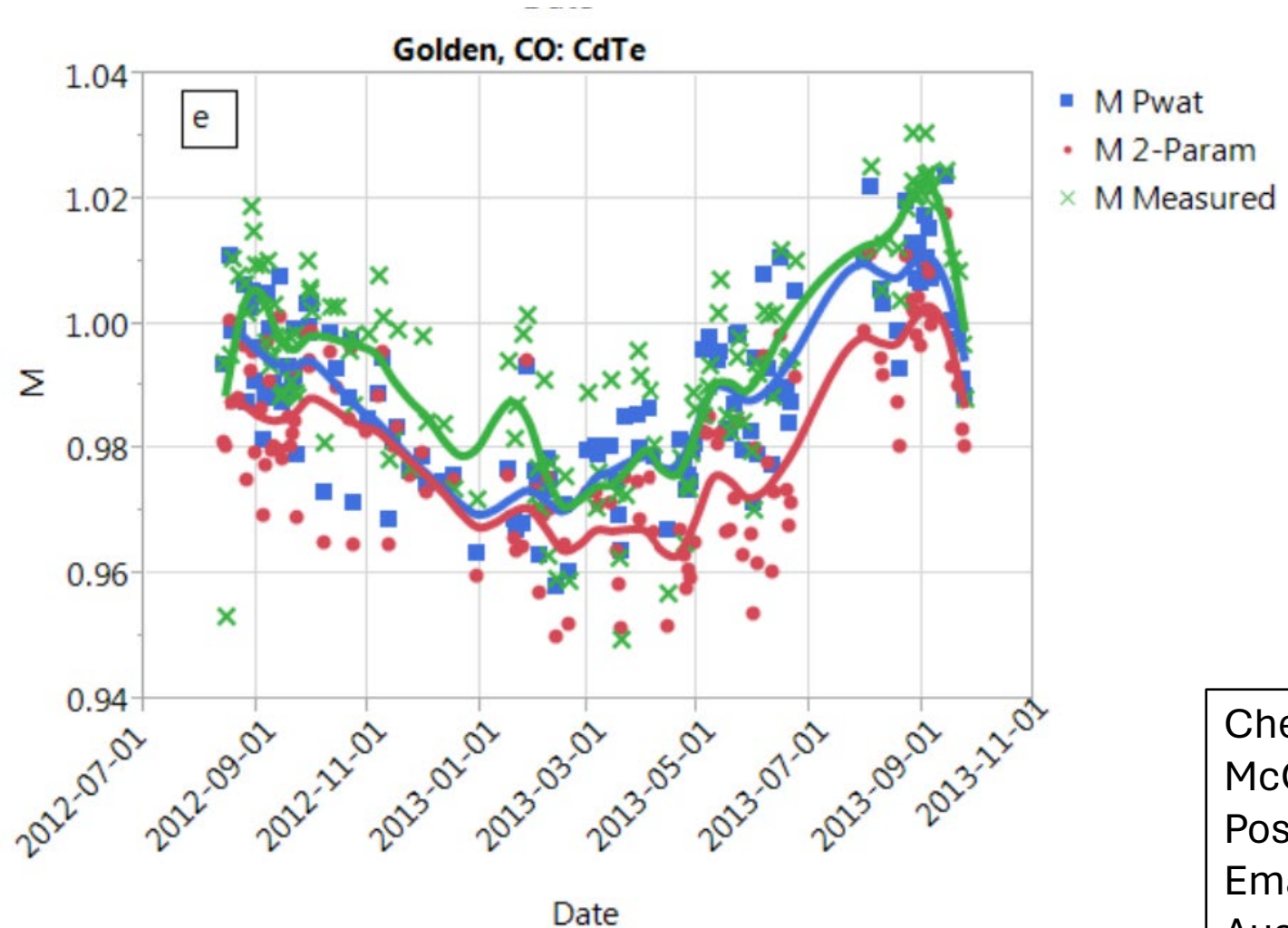
**“Physical Twin”
-CdTe:**

**Effective
Irradiance
correction
needed from
pyranometer
POA**

**Can also use c-
Si reference
cells or CdTe
Modules as
effective
irradiance
sensors.**

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Outdoor CdTe Spectral Corrections to POA Irradiance from FSLR Airmass and PWAT model 2.0



Lee and Panchula, First Solar 2016

Check out
McCarthy
Poster:
Emami and
Auslender

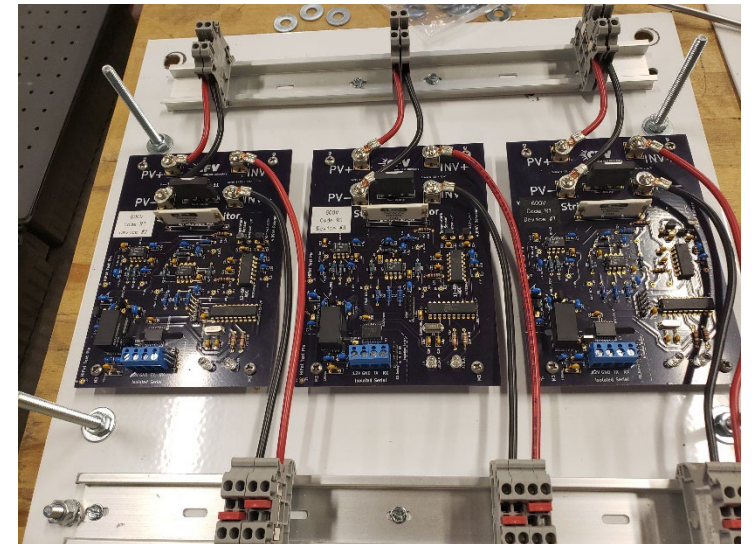
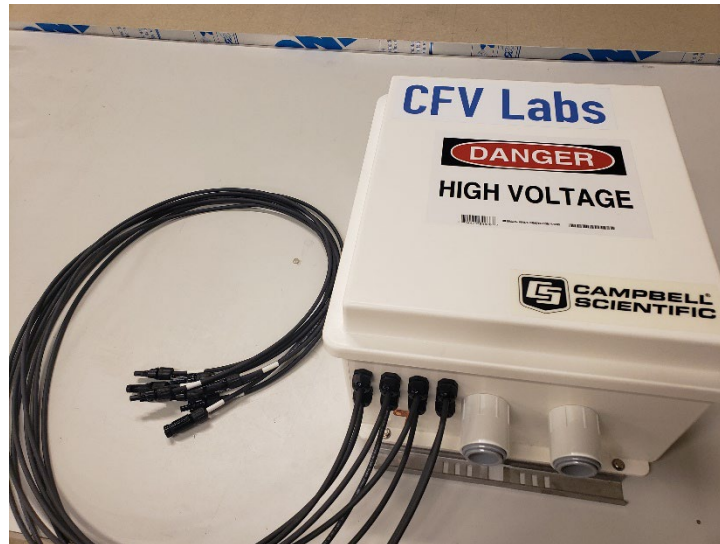
On site CFV 1500 Volt PV Reference String Monitors:

Running in large
PV Plants for
several years

Can be reference
strings for
performance,
degradation,
soiling, etc.

SCADA or Cell
Modem comms

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Summary

- Multiple methods exist to monitor and evaluate DC performance for PV power plants:
 - Flash testing in the lab
 - Field IV measurements
 - “Physical Twin” parallel arrays at CFV
 - On-site instrumented reference strings
- Understanding DC performance can have multiple beneficial impacts on the efficient and timely construction and commissioning of increasingly large and important PV Plant projects.

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