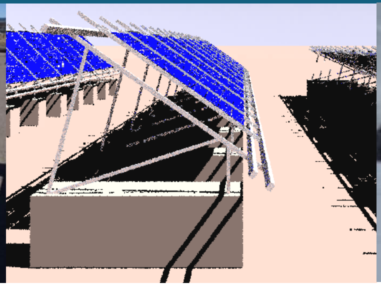
SAND2022-12454C

Early-life degradation analysis of PV module technologies exposed in different climates in the US



PRESENTED BY

Marios Theristis

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PVPG/SLTE Team

Sandia: Bruce H. King (PI), Joshua S. Stein, Charles Robinson

NREL: Chris Deline (co-PI), Dirk Jordan, William Sekulic, Allan Anderberg, Byron McDanold, Josh Parker

FSEC: Hubert Seigneur, Dylan J. Colvin, Joseph Walters

Introduction

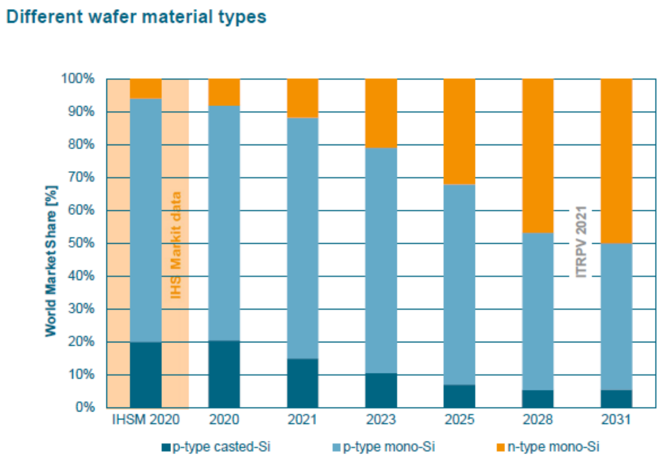
- Cost of PV modules has declined by up to 85% since 2010 [1]

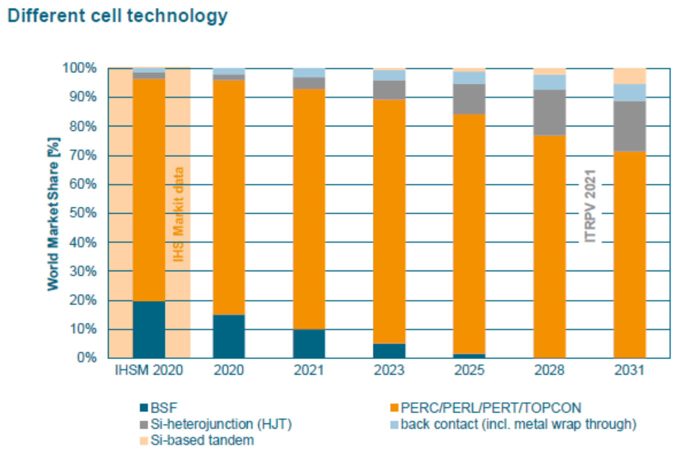
- Module designs and BOM have been altered to achieve these cost reductions

- Common practices assume degradation rates of -0.5%/year to -0.6%/year based on Jordan et al. [2], [3] (~1979 and ~2014)

→ Are **module** degradation rates changing?

→ Do **module** degradation rates vary in different climates?





Figures obtained from ITRPV 2021 [4]

[1] D. Feldman, et al., "US Solar Photovoltaic System and Energy Storage Cost Benchmark: Q1 2020," National Renewable Energy Lab.(NREL), Golden, CO (United States). NREL/TP-6A20-77324,2021.
[2] D. C. Jordan and S. R. Kurtz, "Photovoltaic Degradation Rates—an Analytical Review," *Progress in Photovoltaics: Research and Applications,* vol. 21, pp. 12-29, 2013.
[3] D. C. Jordan, *et al.*, "Compendium of photovoltaic degradation rates," *Progress in Photovoltaics: Research and Applications,* vol. 24, pp. 978-989, 2016.
[4] ITRPV 2021, "International Technology Roadmap for Photovoltaic (ITRPV)," 12th Edition, November 2021.

Approach

- We purchased and fielded 834 modules
  [13 different module types, 7 manufacturers]

- The systems are deployed in the field at 3 climates
  [high desert NM, colder semi-arid CO, subtropical FL]

- Continuous and discreet IV and MPP measurements

- We report on early-life module degradation (< 5 years) based on > 2000 IV curves at STC

- **Onymous** analysis not anonymous

Module selection

- This program represents 55% of the 2020 US market
- Attempted to maintain diversified selection to include different technologies
- Modules with the same model number were sourced from two or more vendors
- Modules were purchased from the open-market to ensure there is no bias
- Modules are continuously being installed since 2016:

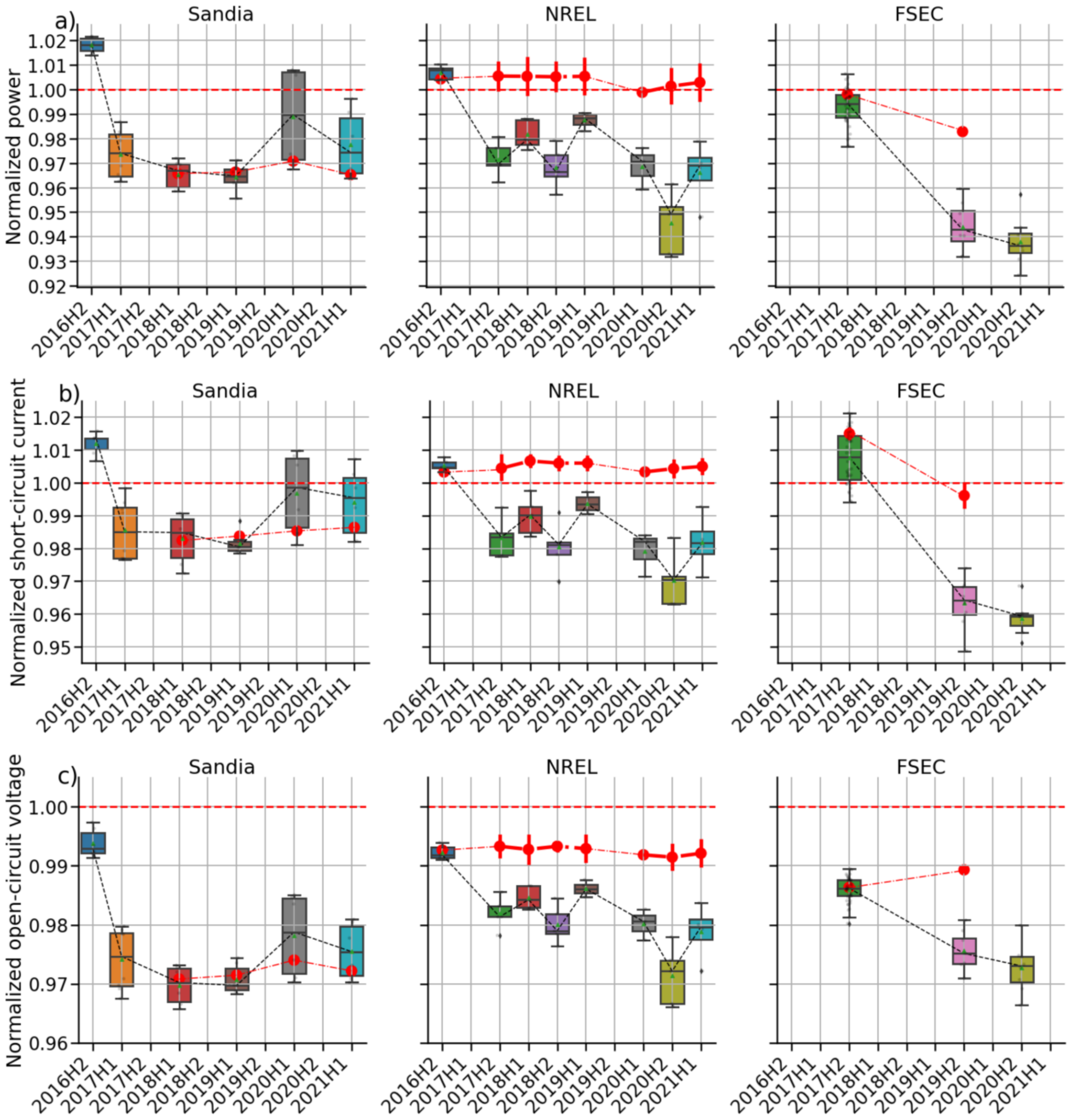
https://pvpmc.sandia.gov/pv-research/pv-lifetime-project/pv-lifetime-modules/

					Arid	Semi-Arid	Subtropical
Company	Model and power rating	Type	Features	Date deployed	Number in NM	Number in CO	Number in FL
Jinko Solar	JKM260P 260W	Poly-Al-BSF	4 busbars	06/2016 (NM) 09/2016 (CO) 09/2017 (FL)	56* (28× 260, 28 × 265)	28	56* (28× 260, 28 × 265)
Jinko Solar	JKM265P 265W	Poly-Al-BSF	4 busbars	10/2016		28	
Trina Solar	TSM-PD05.05 255W	Poly-Al-BSF	4 busbars	10/2016	-	28	-
Trina Solar	TSM-PD05.08 260W	Poly-Al-BSF	4 busbars	06/2016 (NM) 09/2016 (CO) 09/2017 (FL)	56	28	56
Canadian Solar	CS6K-270P 270W	Poly-Al-BSF	4 busbars	10/2017	48	-	-
Canadian Solar	CS6K-275M Quartech 275W	Mono-Al-BSF	4 busbars	10/2017	48	-	-
Canadian Solar	CS6K-300MS Quintech 300W	Mono-PERC	5 busbars	08/2018	-	28	-
Hanwha Q-Cells	Q.Plus BFR-G4.1 280W	Poly-PERC	4 busbars	10/2017	48	28	-
Hanwha Q-Cells	Q.Peak BLK G4.1 290W (NREL) and 300 W (Sandia)	Mono-PERC	4 busbars	10/2017	48	28	-
LG	LG320N1K-A5 320W	N-type Mono-PERT	Bifacial, 12 multi wire busbars	06/2018	48	28	-
Panasonic	N325SA16 325W	N-type Mono-HIT	Bifacial, 4 busbars	06/2018	48	30	-
Mission Solar	MSE300SQ5T 300W	P-type Mono-PERC	4 busbars	05/2019	48	-	-
Mission Solar	MSE360SQ6S 360W	P-type Mono-PERC	4 busbars	12/2018	-	20	
Site Totals					448	274	112
Program Total					834 modules		

Flash test results from selected modules

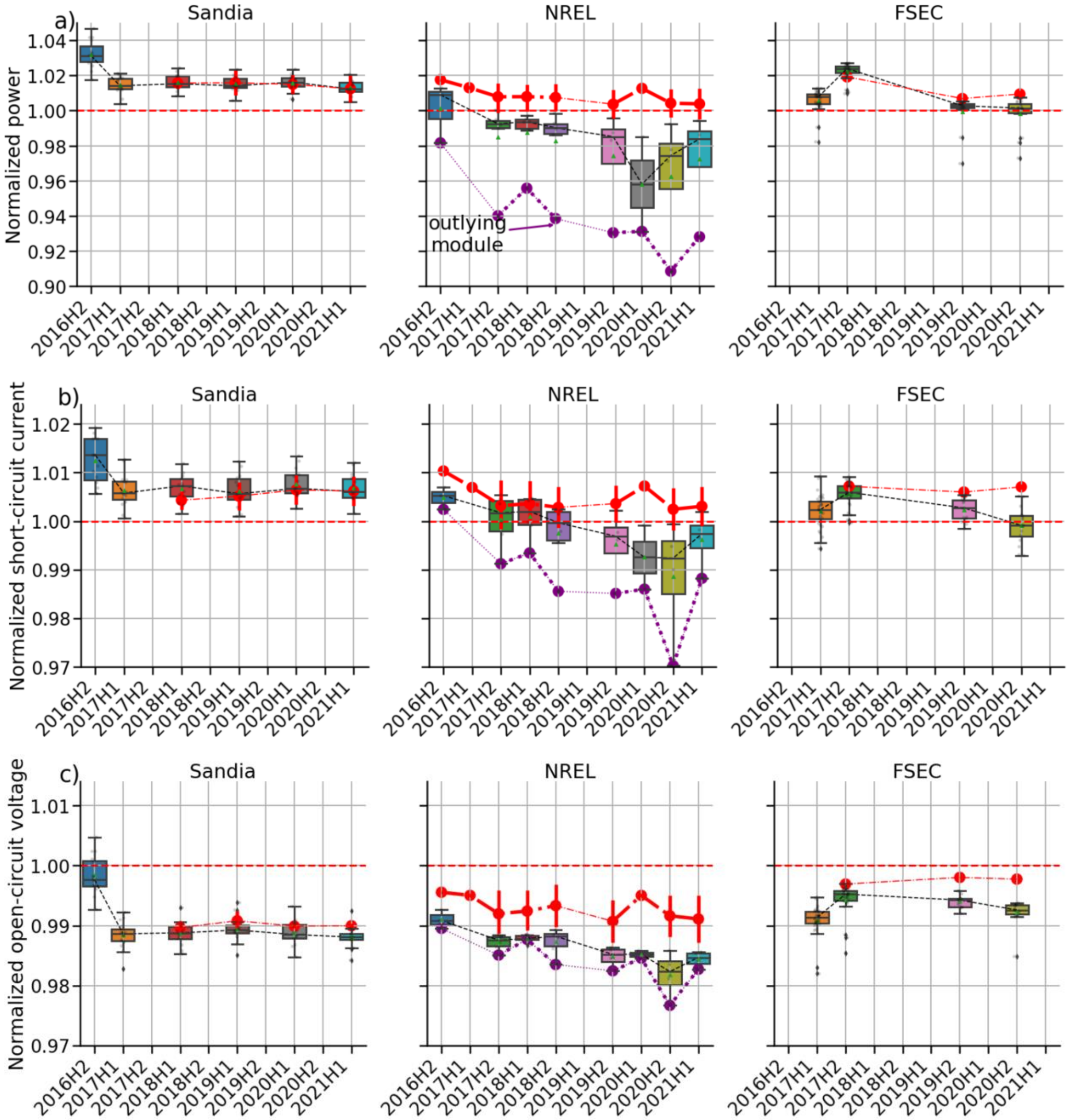
Jinko Solar 260

- Steep drop in Y1 followed by a relatively unstable behavior with a trend indicating LeTID in Al-BSF
- Seasonality effects evident in NREL flash tests
- NREL and FSEC indicate that degradation is greater in Isc
- Performance loss is greater in the subtropical climate of FL as compared to the high-desert in NM



Trina Solar 260

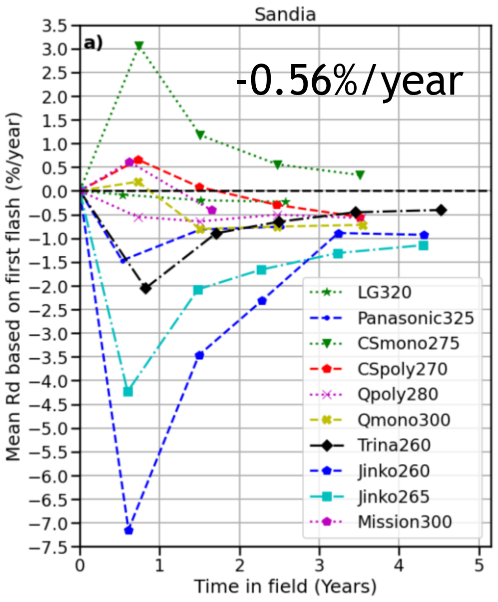
- Modest power degradation with one exception
- Outlying module demonstrated an LeTID-like behavior
- Even when a same module is purchased, there is a possibility of ending up with different BOM and thus, a potential different behavior
- Overall power change ranged from -2.5% to -0.6% whereas the outlying module exhibited -5.3%

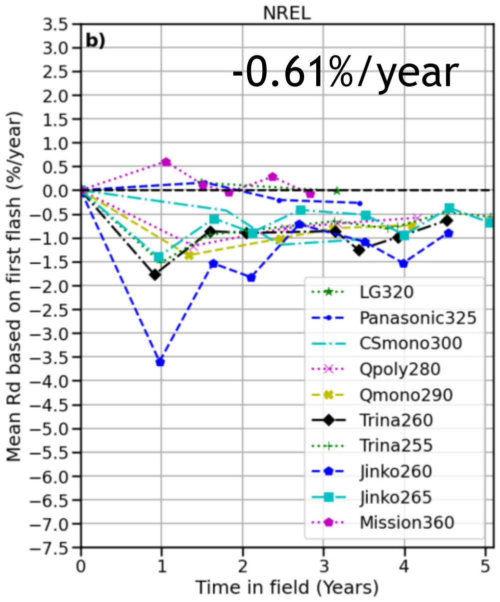


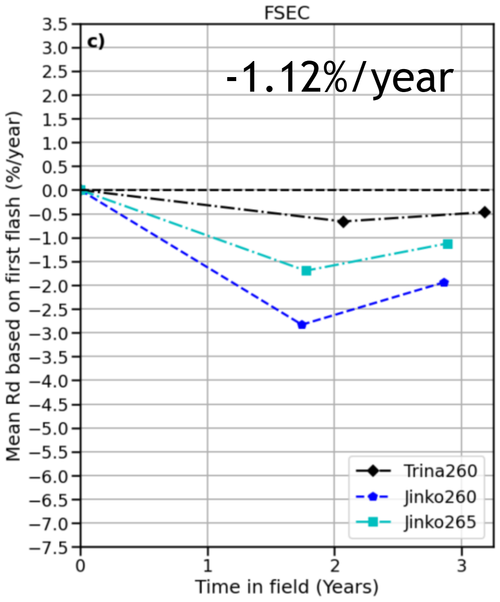
Degradation rates

Module degradation rates in three climates

Based on first post-stabilization ratings







Range:
-1.9%/year (Jinko260) to
+0.3%/year (CSmono275)

-0.8%/year in the high-desert climate of NM
-0.7%/year in the semi arid climate of CO
-1.2%/year in the subtropical climate of FL

Mean and median values around -0.6%/year

Few points for discussion

Discussion point #1

How are we doing with respect to the absolute values of Rd and warranties?

- Costs dropped, technology evolved, but Rd values do not seem to be affected, which is an encouraging outcome
- There are still opportunities to reduce Rd to levels that enable longer PV module lifetimes
- Assuming Rd values cease to change:
  - 6 out of 23 (or 26.1%) systems are projected to exceed the warranty limits (i.e., Rd < -0.8%/year) and qualify for module replacements
  - 12 out of 23 (or 52.2%) systems demonstrated the potential of achieving lifetimes beyond 30 years (i.e., Rd > -0.6%/year)

Discussion point #2

Highly nonlinear degradation behavior

- Unnecessary O&M alerts might be triggered when expectations differ in any year

- Understanding that such nonlinearities are not uncommon in the first years; tend to converge after ~4 years

- Applying statistical approaches that consider nonlinearities might help; here are some examples:

1112 IEEE JOURNAL OF PHOTOVOLTAICS, VOL. 10, NO. 4, JULY 2020

Nonlinear Photovoltaic Degradation Rates: Modeling and Comparison Against Conventional Methods

Marios Theristis, Andreas Livera, C. Birk Jones, George Makrides, George E. Georghiou, and Joshua S. Stein

IEEE JOURNAL OF PHOTOVOLTAICS, VOL. 11, NO. 4, JULY 2021 1087

New PV Performance Loss Methodology Applying a Self-Regulated Multistep Algorithm

Sascha Lindig, Atse Louwen, David Moser, and Marko Topic

IEEE JOURNAL OF PHOTOVOLTAICS, VOL. 11, NO. 6, NOVEMBER 2021 1511

Comparative Analysis of Change-Point Techniques for Nonlinear Photovoltaic Performance Degradation Rate Estimations

Marios Theristis, Andreas Livera, Leonardo Micheli, Julián Ascencio-Vásquez, George Makrides, George E. Georghiou, and Joshua S. Stein

Discussion point #3

Degradation rates are worse in the subtropical climate of FL, as compared to the high-desert in NM

- Taking into account Jinko/Trina modules only we found mean Rd of:
  - -0.8%/year in the high-desert climate of NM
  - -0.7%/year in the semi-arid climate of CO
  - -1.2%/year in the subtropical climate of FL
- Damp heat conditions of FL are more challenging for PV as compared to the seasonal thermal cycling and high UV in NM and CO
- More samples are required to verify such weather dependent findings

Thank you!

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RESEARCH ARTICLE

PROGRESS IN PHOTOVOLTAICS WILEY

Onymous early-life performance degradation analysis of recent photovoltaic module technologies

Marios Theristis[1] | Joshua S. Stein[1] | Chris Deline[2] | Dirk Jordan[2] | Charles Robinson[1] | William Sekulic[2] | Allan Anderberg[2] | Dylan J. Colvin[3] | Joseph Walters[3] | Hubert Seigneur[3] | Bruce H. King[1]

Sandia National Laboratories

SOLAR ENERGY TECHNOLOGIES OFFICE
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