New Cells, New Issues

*creating trust, **driving progress***

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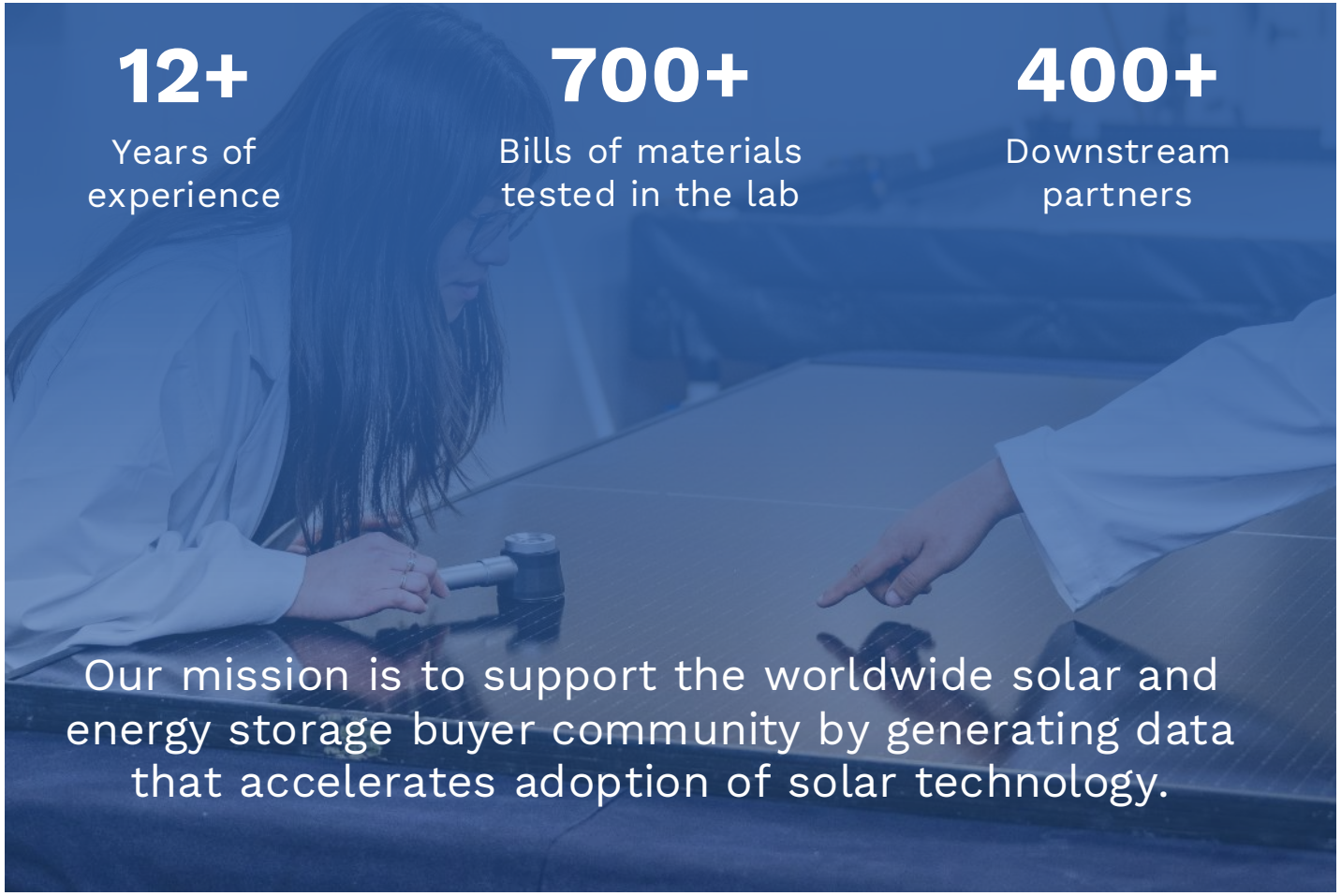
Duramat Workshop

Denver, CO

Oct 8, 2025

Kiwa PVEL is the Independent Lab of the Downstream Solar Market



Services at a glance:

- Extended reliability and performance testing for PV modules
- Batch testing of PV modules
- Outdoor testing of PV modules, inverters and energy storage
- Data services for PV buyers and investors

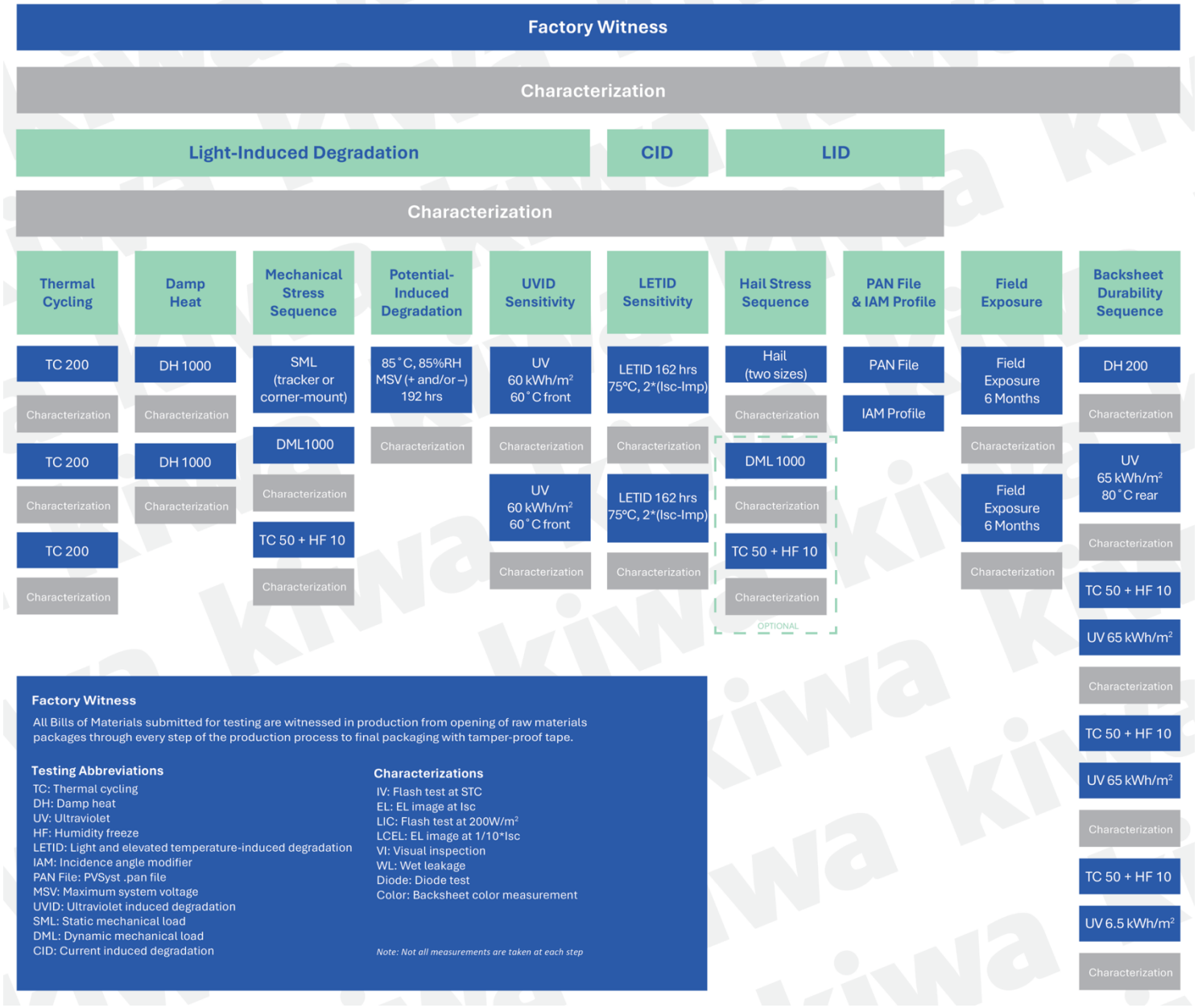
See more details at kiwa.com/pvel

PQP Test Sequence

The PQP evolves every two years based on feedback from Kiwa PVEL's downstream partners, module manufacturers, and the industry's collective understanding of module failure modes and test mechanisms.

The most recent update introduced the new UVID test and streamlined many of the tests leading to faster execution of PQP projects.

Learn more about the current version of the PQP test plan at kiwa.com/pvel/pqp.

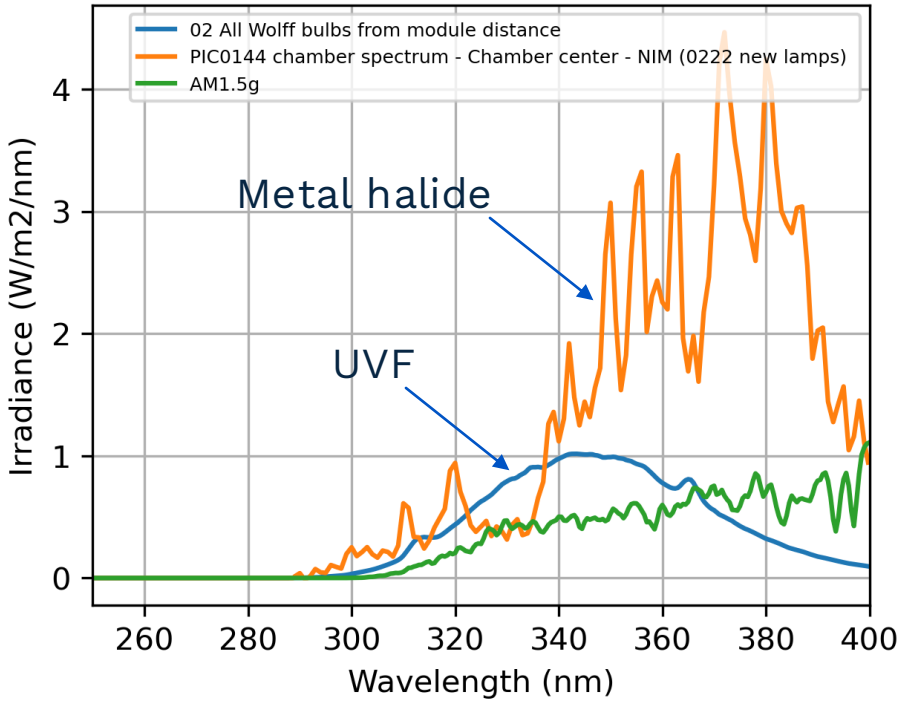


Outline

1. UVID
    1. Accelerated test data
    2. FE data.
    3. Lit review -- how to fix UVID.
    4. Long UVID
2. Current/upcoming module reliability concerns.
    1. Polyfinger
    2. Bigger cells + Layout issues.
    3. Perovskites

UVID summary

- PVEL's UVID120 test
  - 60 C black panel temperature
  - Short-circuit
  - Metal halide: 120 kWh/m2 of total UV exposure.
  - UV Fluorescent: 55 kWh/m2 of total UV exposure
  - Damage model based on Monte Carlo analysis of best-available evidence in 2024.

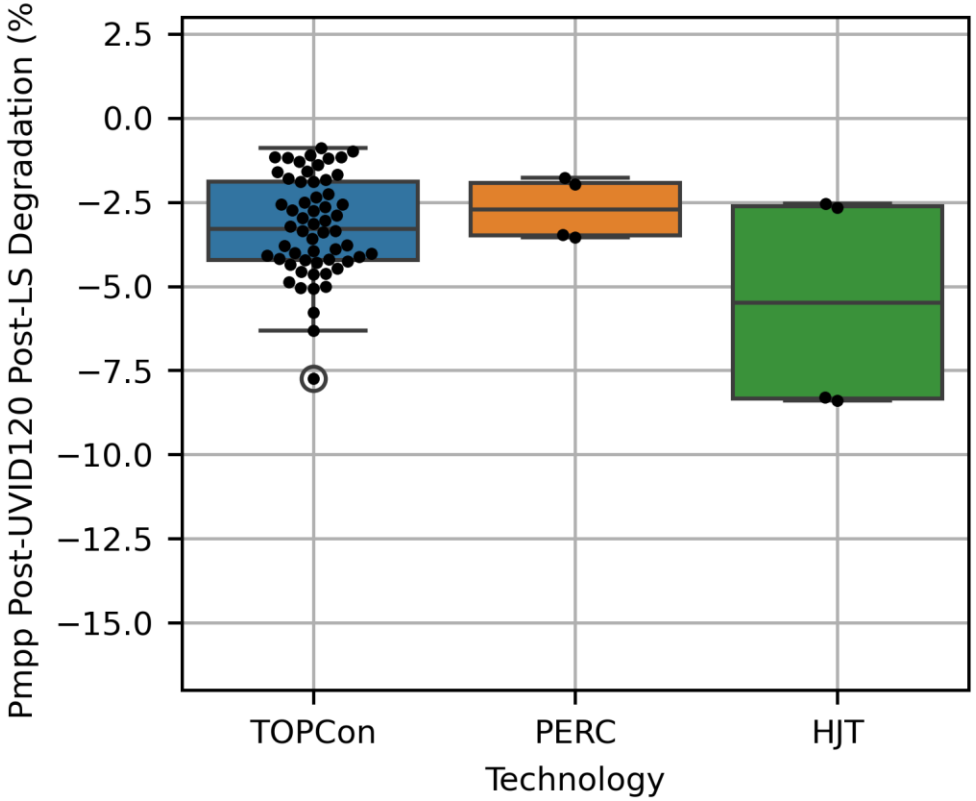


Light soak is crucial to get accurate results, but only on some samples.

- Most recent samples: data all taken in 2025 using Light soak stabilization post UVID..
- Many samples not affected by LS, but some are very affected.
- Limiting time from UV chamber to characterization to <48 hours does most of the work for you!

UVID is still a major reliability concern for all technologies (even when properly accounting for recovery issues).

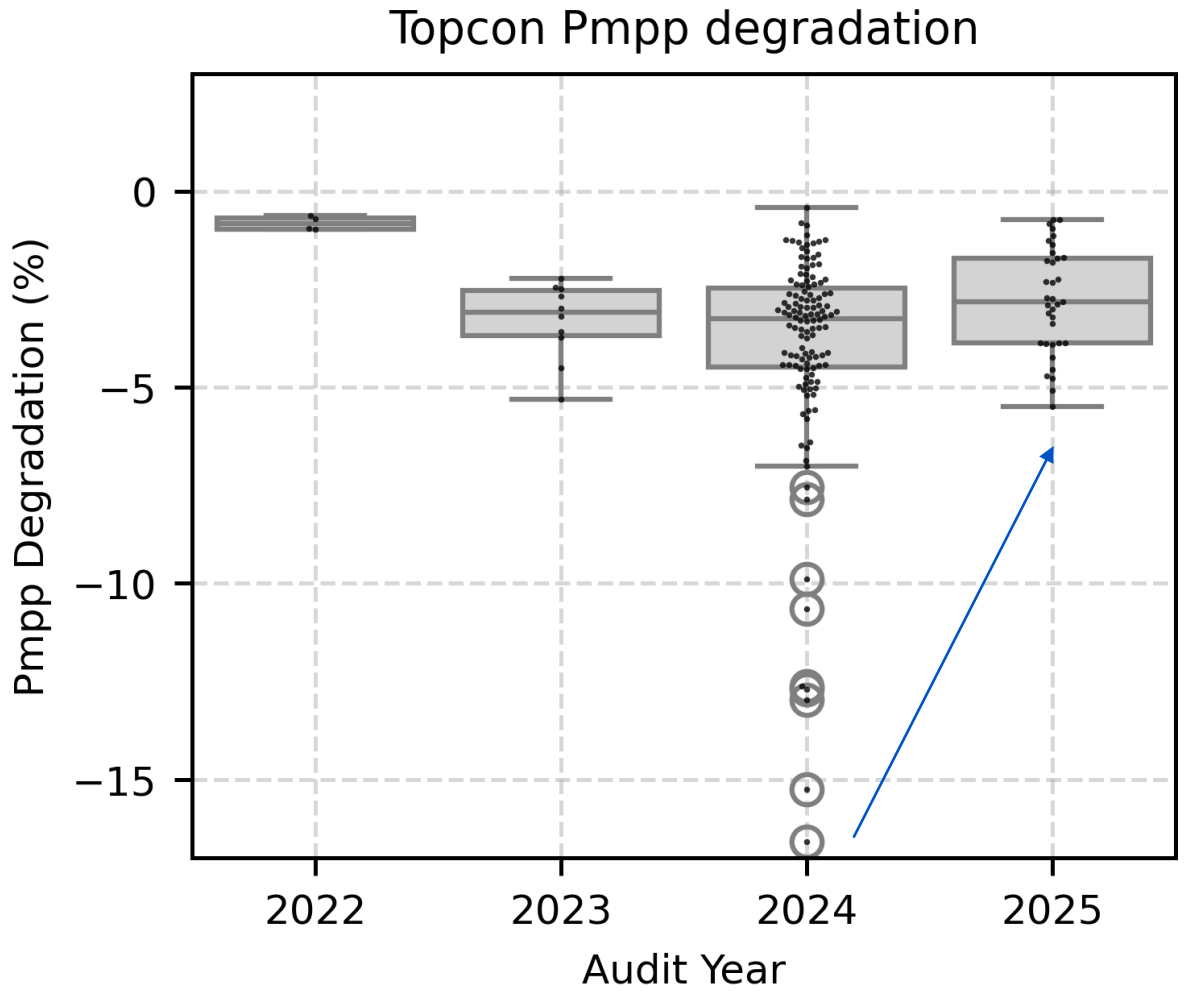
Typical degradation seen in ~1.5 year equivalent test is -2 to -4%.



UVID stability improved, but is not solved

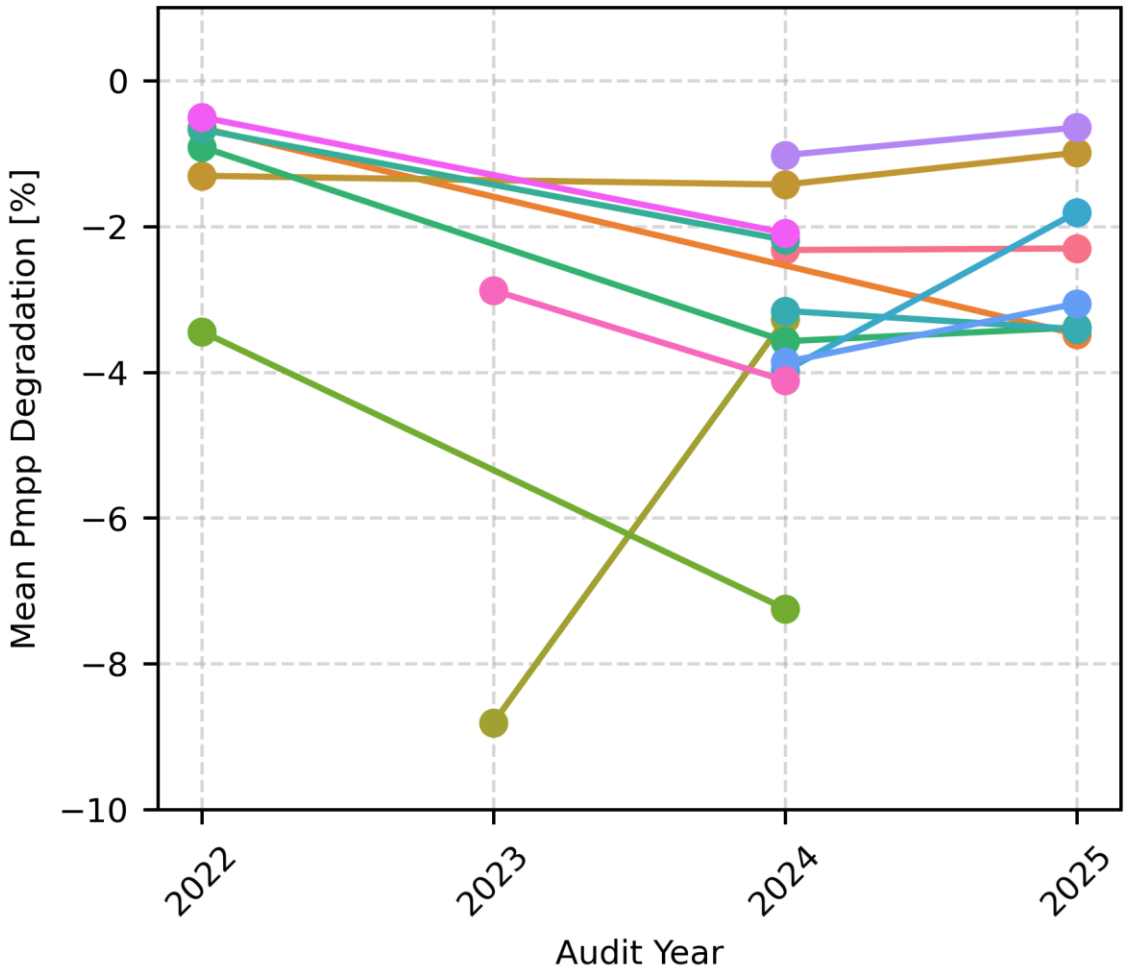
- Note: some big outliers are partially a result of dark metastability.
- From 2024-2025, outlier tail disappeared and the median improved.
- Some improvement is a result of a better understanding of dark metastability.

UVID stability has improved, but still only 31% of modules have less than 2% degradation in UVID120.



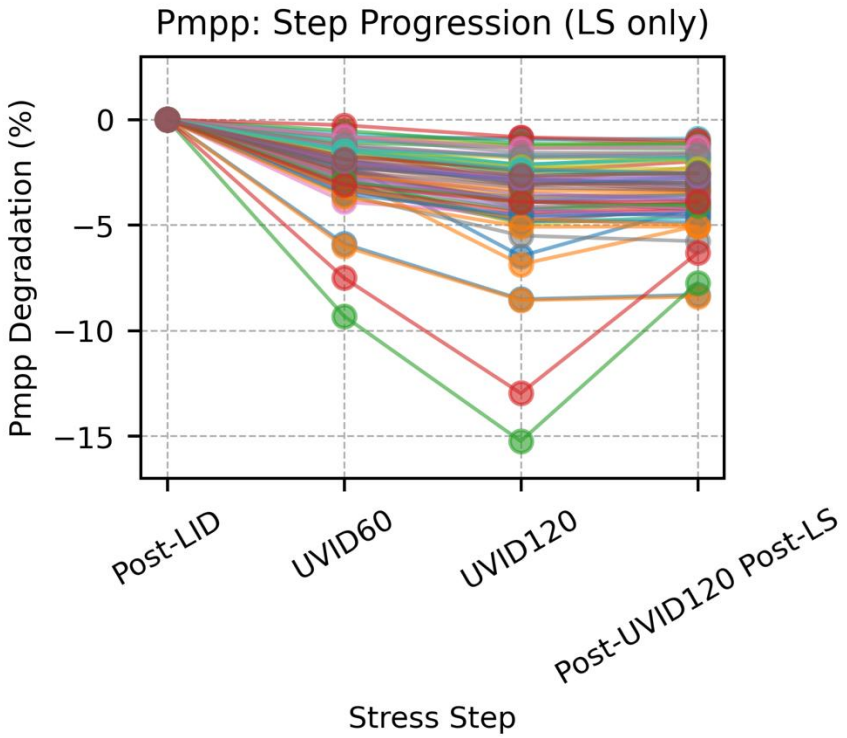
Learning for individual cell supppliers

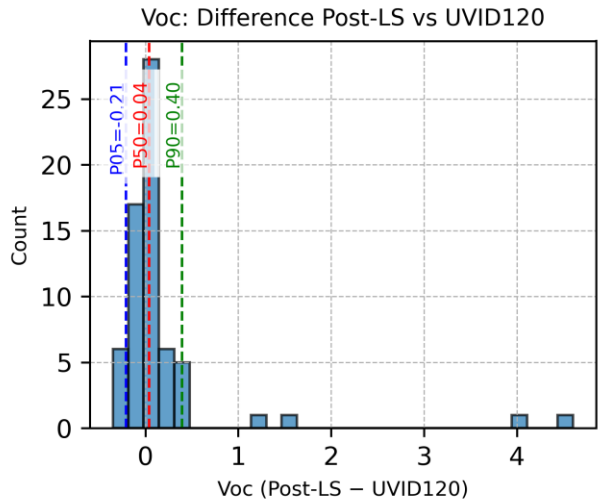
- Each line is an individual cell supplier.
- Most cell suppliers have better performance in 2025 compared to 2024.

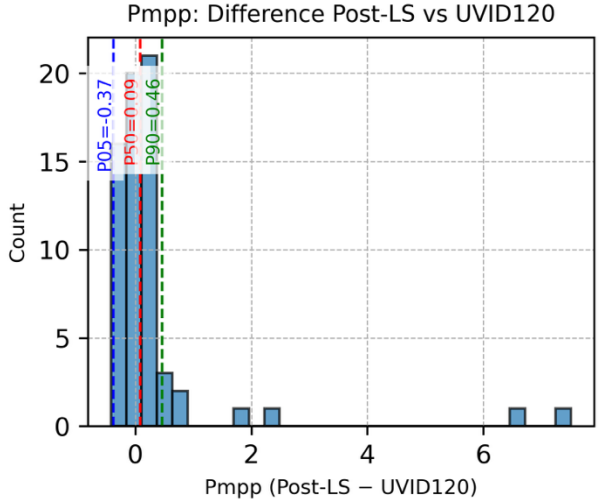


Light soak is important to perform after UVID120 on a small fraction of modules.

- UVID causes modules to have a dark metastability: power degrades in the dark, but is recoverable.
- Kiwa PVEL implemented a LS stabilization step (0.1 or 0.5 kwh/m2 full spectrum)
- Many samples not affected by LS, but some are very affected.
- By limiting time from UV chamber to characterization to <48 hours, most modules don't change much.



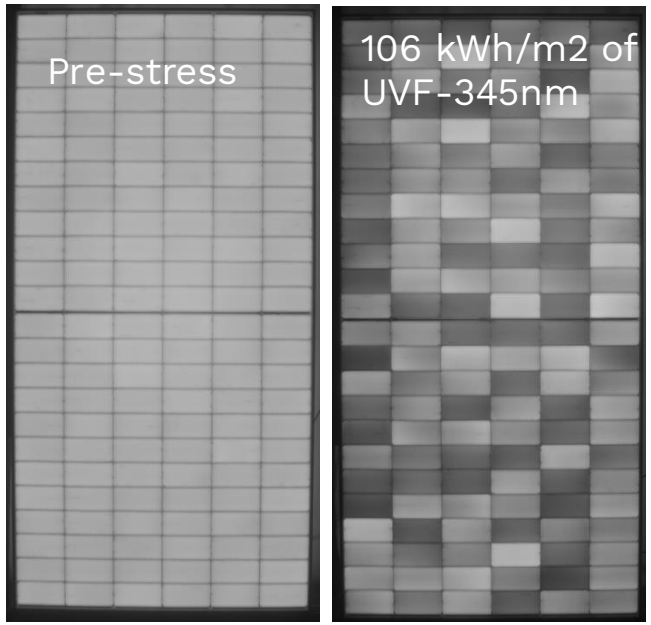


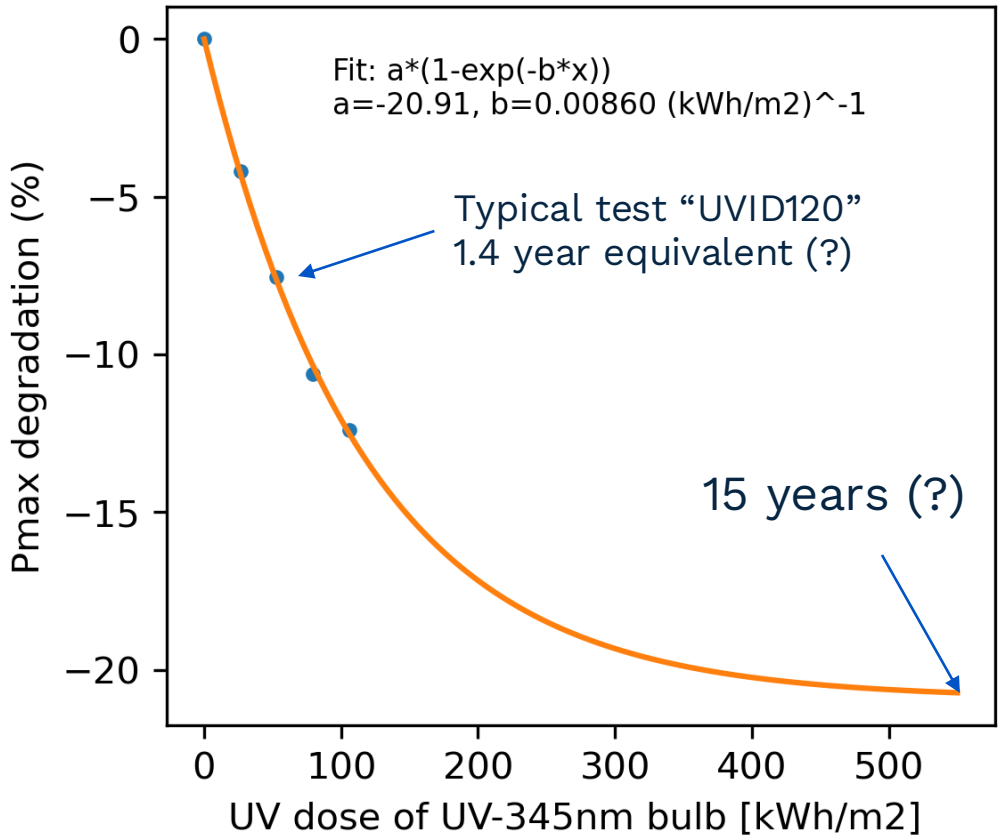


A few samples show significant improvement after light soak stabilization. Most change <0.4%

Long UVID

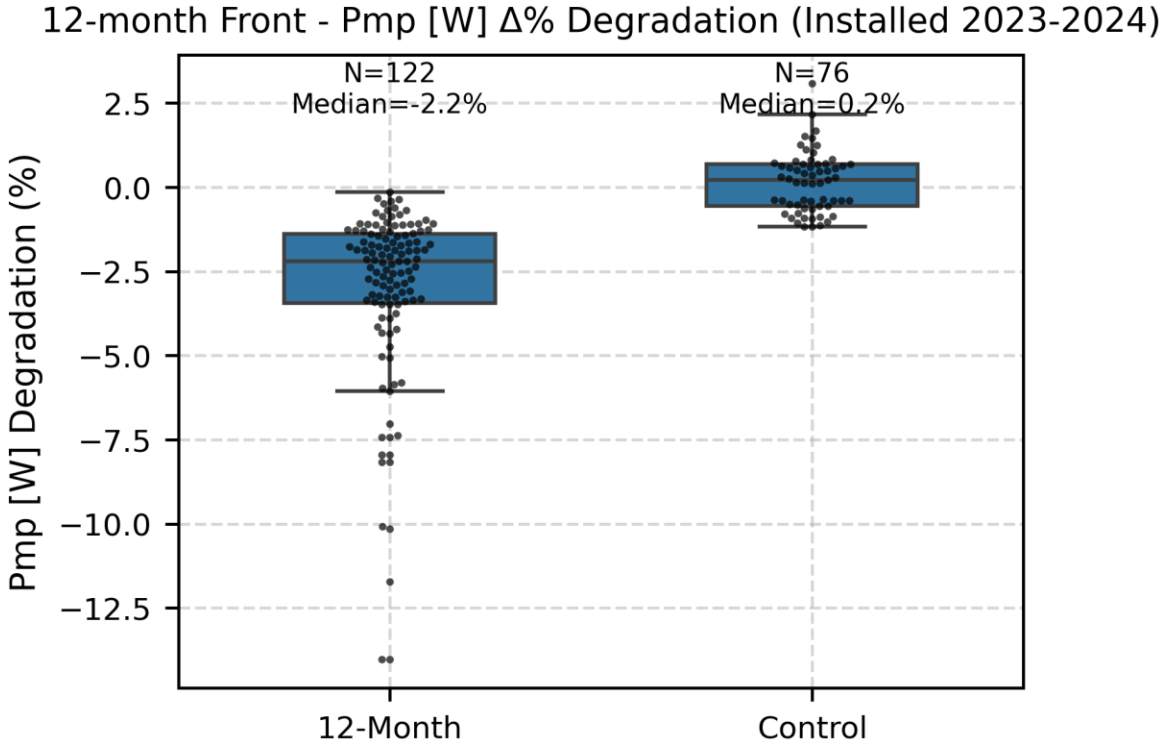
- Module: Industrial TOPCon with high UV sensitivity
- Extrapolated using exponential fit.
  - Saturation expected after approx. 15 years of field aging (550 kWh/m2 of UV-345nm bulbs)
- Long term effect?
  - Module that loses -7.5% after “UVID120” expected to saturate at -21% power degradation.





Field Exposure

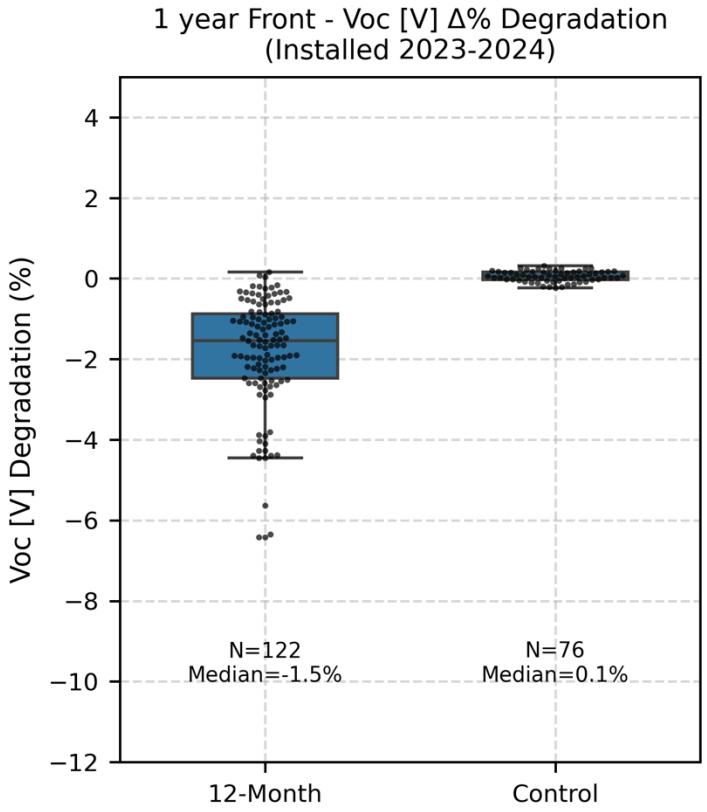
- PVEL performs 1 year outdoor exposure in Davis CA.
- **1 year Pmp degradation has a median of -2.2%**

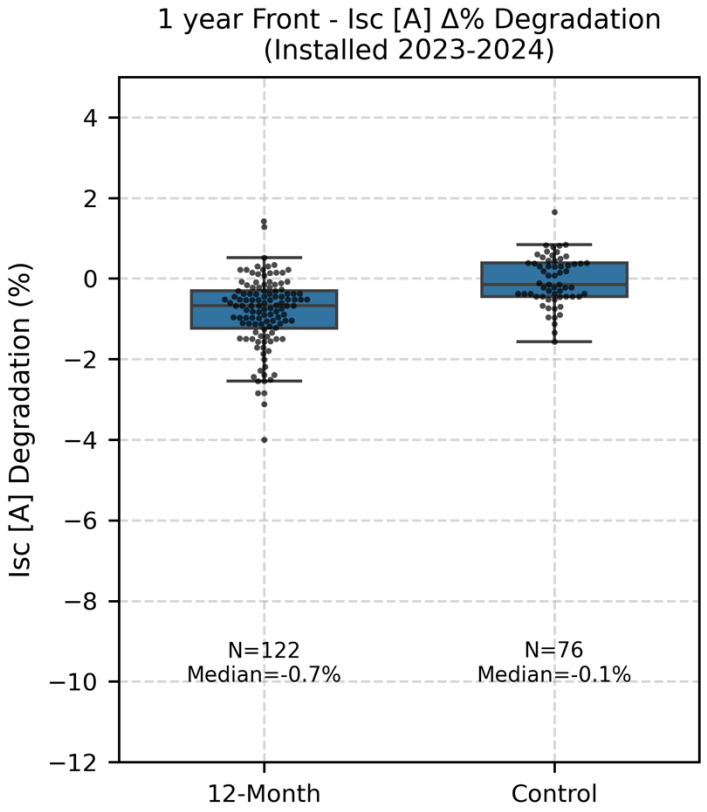


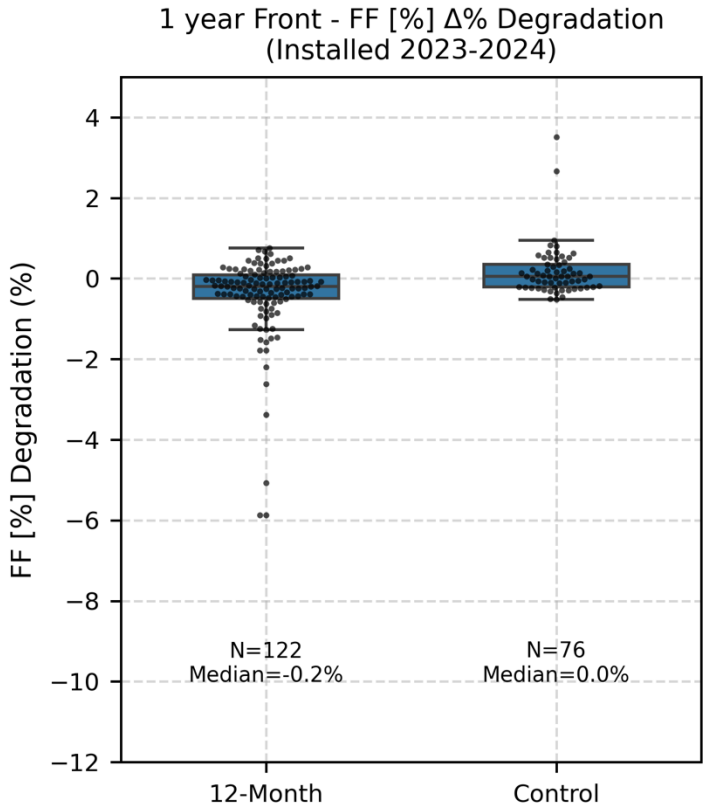
Most modules tested **would not meet** a <1.0% degradation warranty in the first year.

Voc degradation is the primary driver of Field Exposure degradation.

- For most modules, FF degradation is low.
- Pmp degradation is driven by Voc and Isc degradation.
- Voc degradation is not affected by soiling, and is expected to be very trustworthy.
- Median Voc degradation: -1.5%! Outside of warranty claims.

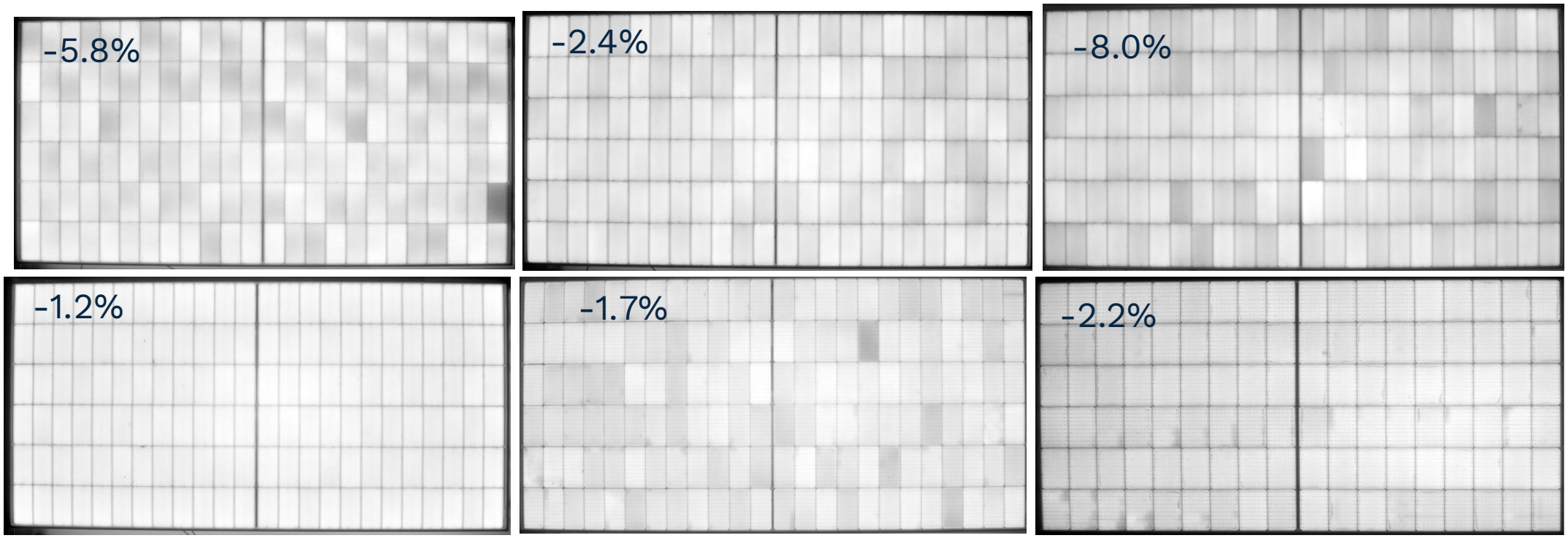






Post 1 year FE, most modules show signs of UVID (checkerboarding)

- For many modules, UVID signature is clearly visible in EL post 1 year exposure.
- (Note some of these modules were not light soaked prior to EL and flash)

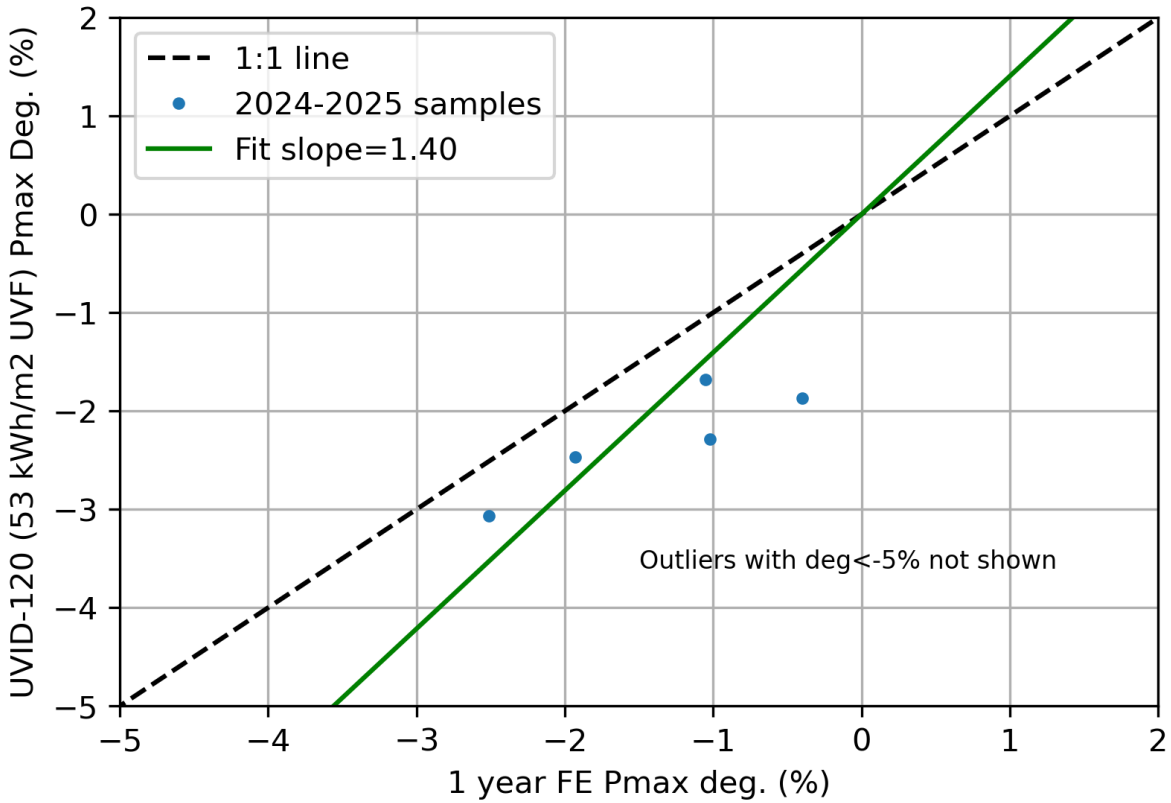


Somewhat random selection of 6 recent FE projects

UVID and FE are correlated

- 2 modules experienced UVID120 (53 kWh/m2 of UVF-345nm). Results averaged.
- 2 modules underwent 1 year outdoor exposure in Davis CA. Results averaged.
- Found more degradation in UVID120 (53 kWh/m2 of UVF-345nm).

- UVID120 (53 kWh/m2 of UVF) correlates with 1.4 years outdoors in Davis CA.
- UV dose received in UVID120 is around 0.5-0.7 years equivalent.

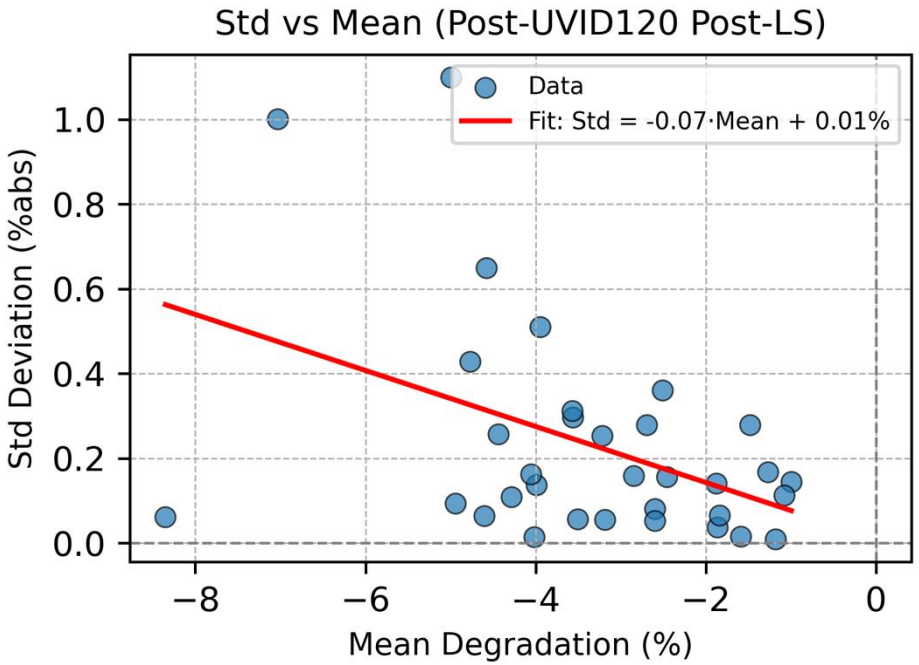


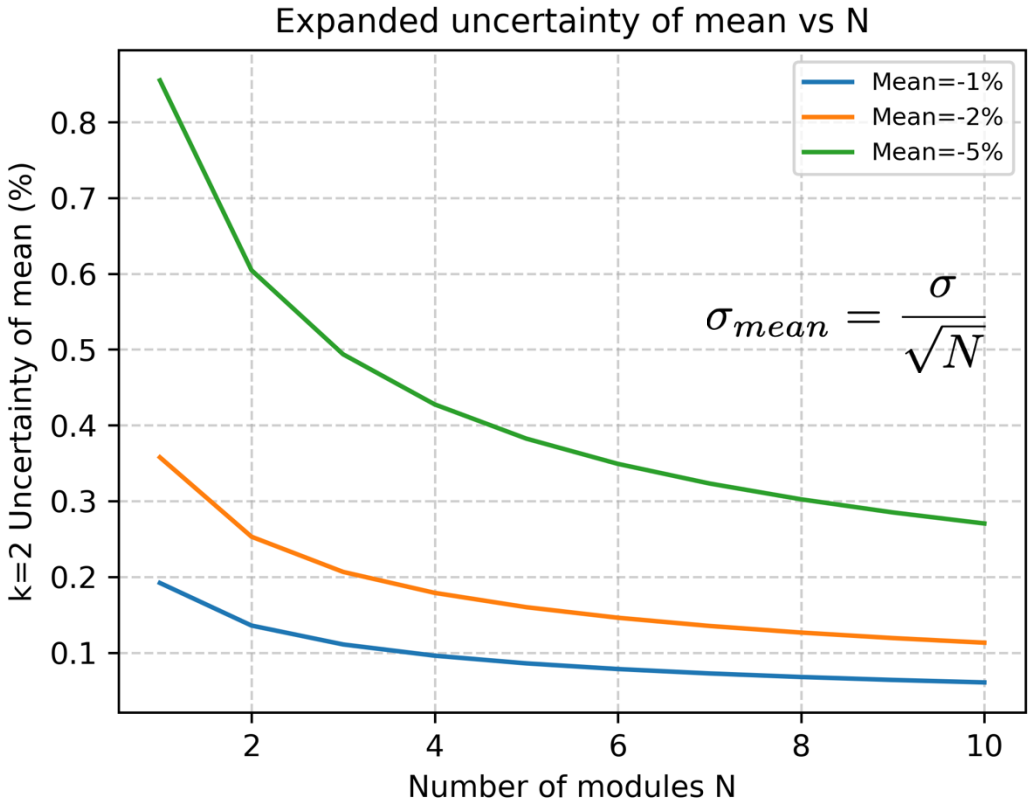
Hypothesis: UVID-120 is accelerated because of short-circuit condition and the lack of visible light in the UV chamber.

How many samples needed for UVID?

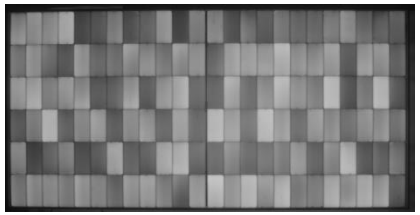
- The std of the measured UVID120 (2 modules tested) depends on the amount of degradation seen.
- With a mean degradation of -2% and 2 samples tested, the k=2 uncertainty of the mean is -0.25% abs.

Testing 2 modules is enough for UVID: uncertainty in degradation is ~15% of degradation value



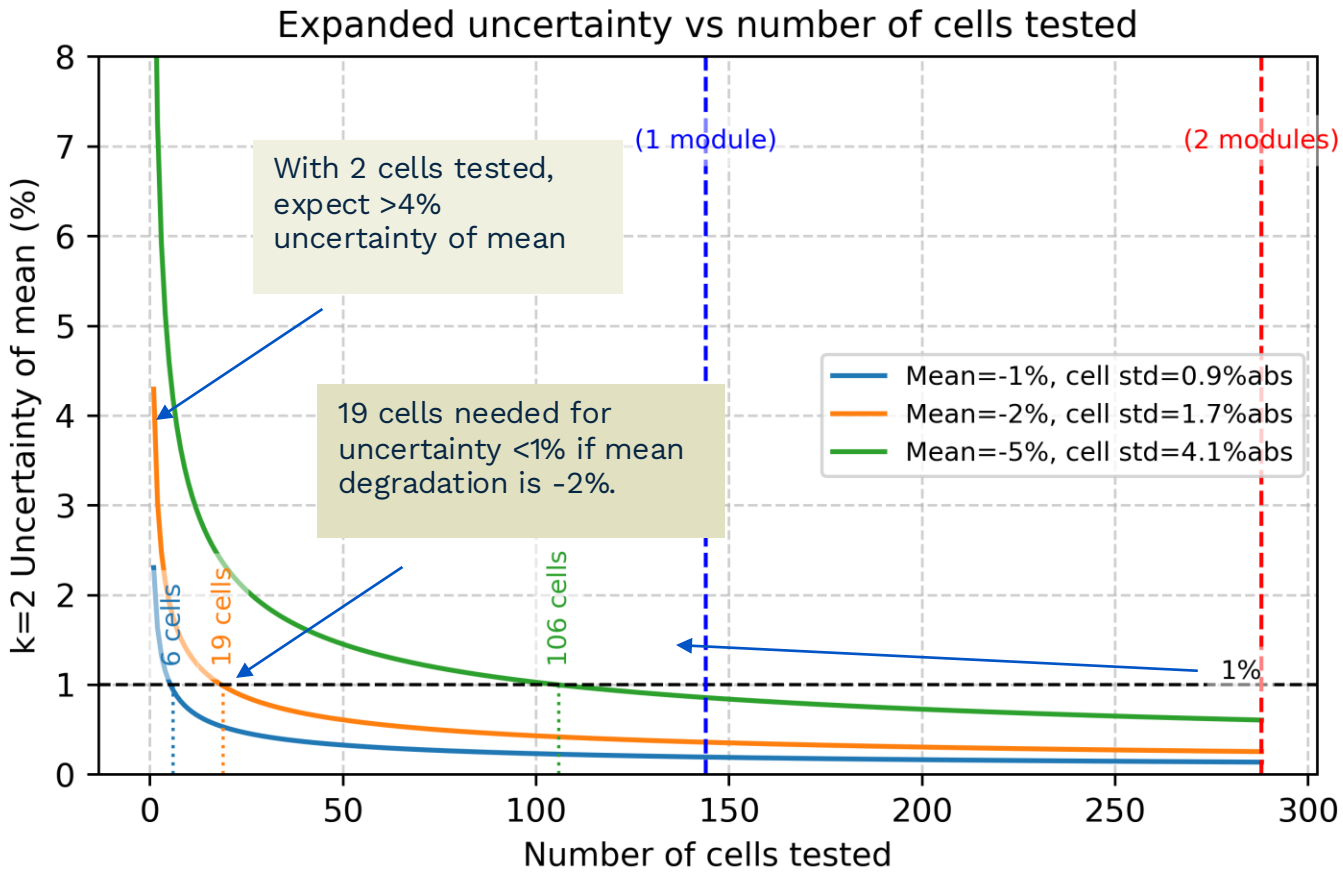


How many cells needed for testing UVID?



Make sure you have a big enough sample size for the expected size of the effect. (i.e. don't do a round-robin with two cells!)

- People often want to test individual cells in order to compare different light sources, different cells, OC/MPP/SC, etc.
- The voltage of the module is very close to the number of cells times average cell voltage.
- Note: we observe degradation randomly distributed even in a single module.
- Can extrapolate from our measured uncertainties at 2 modules w/144 cells to determine the uncertainty of the mean when testing a few cells.



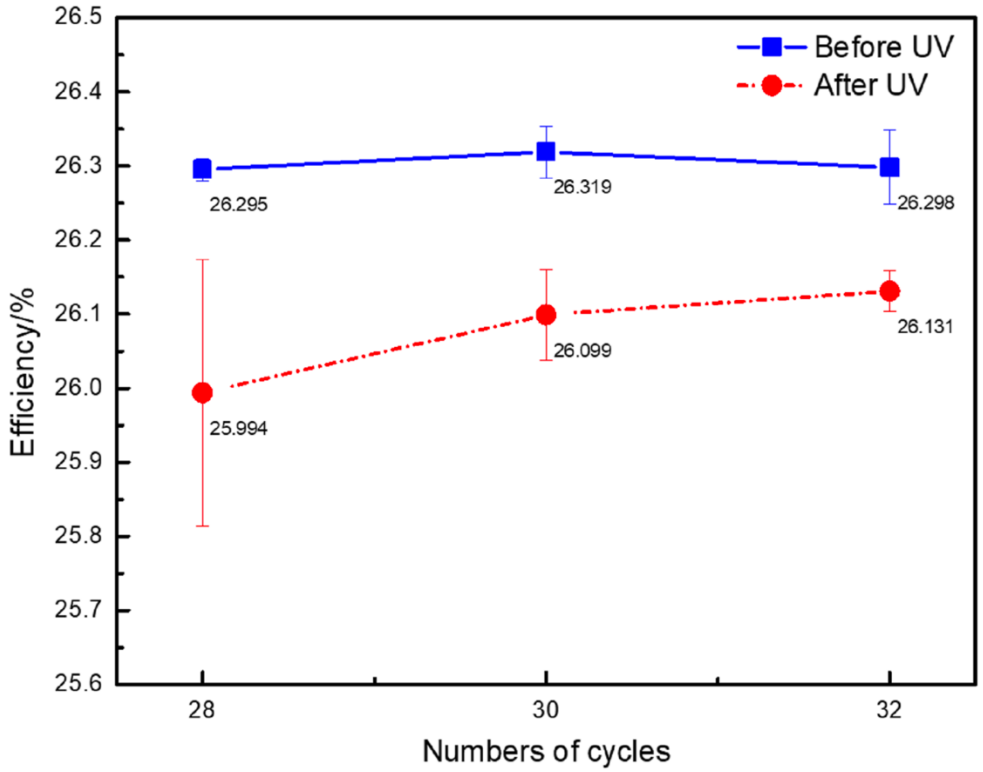
For UVID experiments on cells: 10 cells per group are required to make a statistically significant (95%) comparison between a group of cells with -2% and -5% degradation.

Note: maybe some root pi's missing…

How to fix UVID

- **Finding**: UVID rate drops by ~half with an additional 0.5 nm of AlOx on the front of the cell.
- (~0.125 nm layer thickness per ALD cycle)

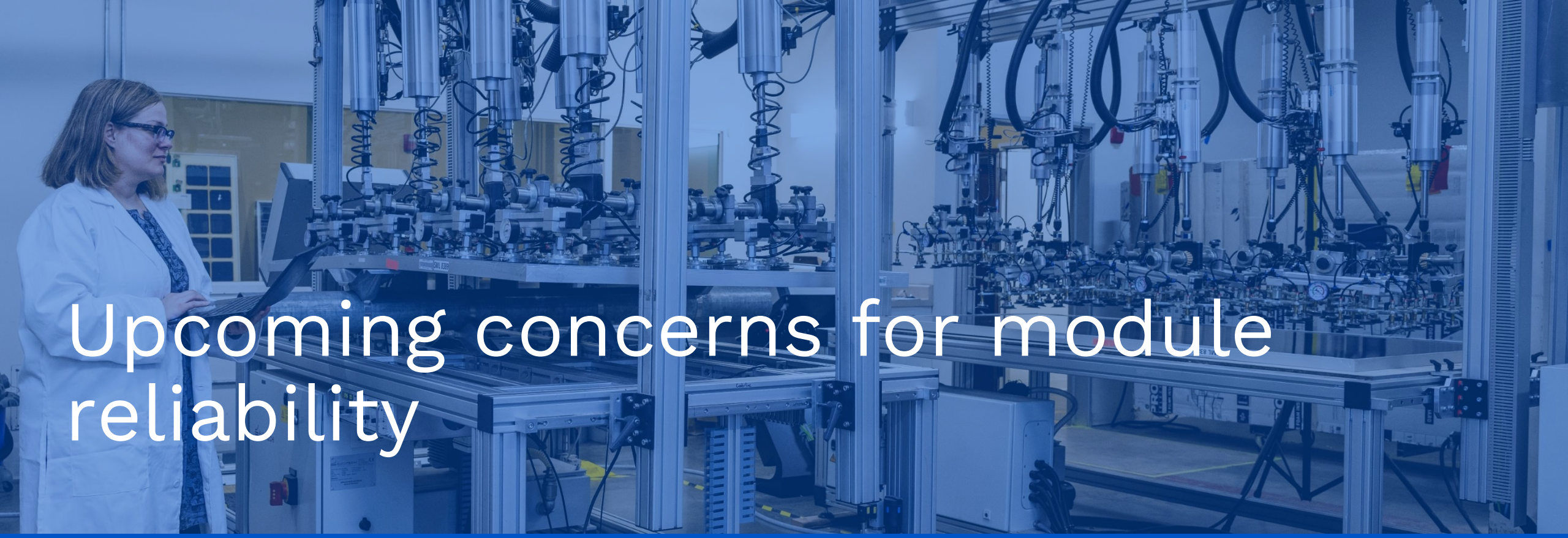
- There are now proposals for UVID mechanism by various authors.



[1] Wenjing Xu, Pengyu Zhou, Qi Xiu, Xianbang Xing; UV degradation analysis of TOPCon cells. AIP Advances 1 February 2025; 15 (2): 025010. https://doi.org/10.1063/5.0247683

[2] Khan, M. U., Sen, C., Pollard, M., Huang, T., Gao, M., Lv, R., Yu, Y., Wu, X., Wang, H., Wang, X., & Hoex, B. (2026). UV-induced degradation in TOPCon solar cells: Hydrogen dynamics and impact of UV wavelength. Solar Energy Materials and Solar Cells, 294, 113895. https://doi.org/10.1016/j.solmat.2025.113895

[3] Li, Z., Yu, K., Zhu, Q., Wang, L., Chen, Y., Huang, J., Zhou, G., Sun, X., Gao, J., & Zhou, L. (2025). UVID of TOPCon solar cells: Effect of the front passivation Al_2O_3 layer thickness and recovery by different processes. Solar Energy Materials and Solar Cells, 289, 113691.



Upcoming concerns for module reliability

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Polyfinger is coming…

Not just an AI problem ☺

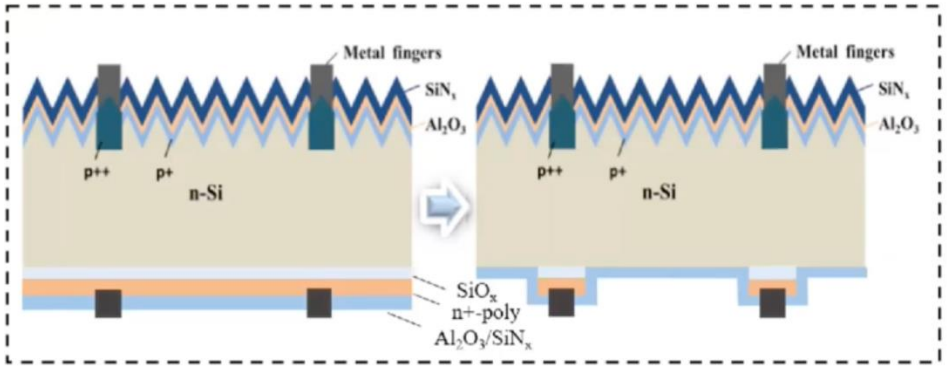
- Poly-Si protects the cell from UV.
- Investigation of backside UV would be important.

Polyfinger tech results in higher power (+0.15%abs), but is expected to increase the backside sensitivity to UV.

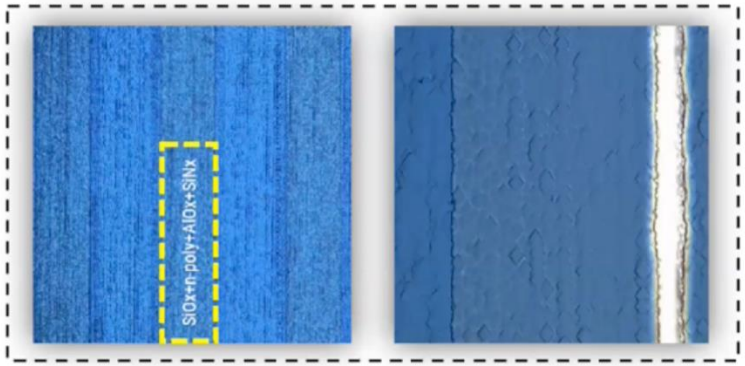
N-type Cell Efficiency Improvement – Poly-finger

DMEGC SOLAR

➢ The structures of rear poly-finger



➢ Poly-finger 3D microscope image



➢ I-V parameters of the cells

Sample	η (%)	V_{oc} (mV)	I_{sc} (A)	FF (%)	R_s (mΩ)
Baseline	-	-	-	-	-
Poly-finger	+0.15	+0.5	+0.11	-0.23	+0.019

☐ To further reduce the parasitic absorption of poly-Si, laser ablation of non grid region poly can effectively improve the I_{sc} of the solar cell.

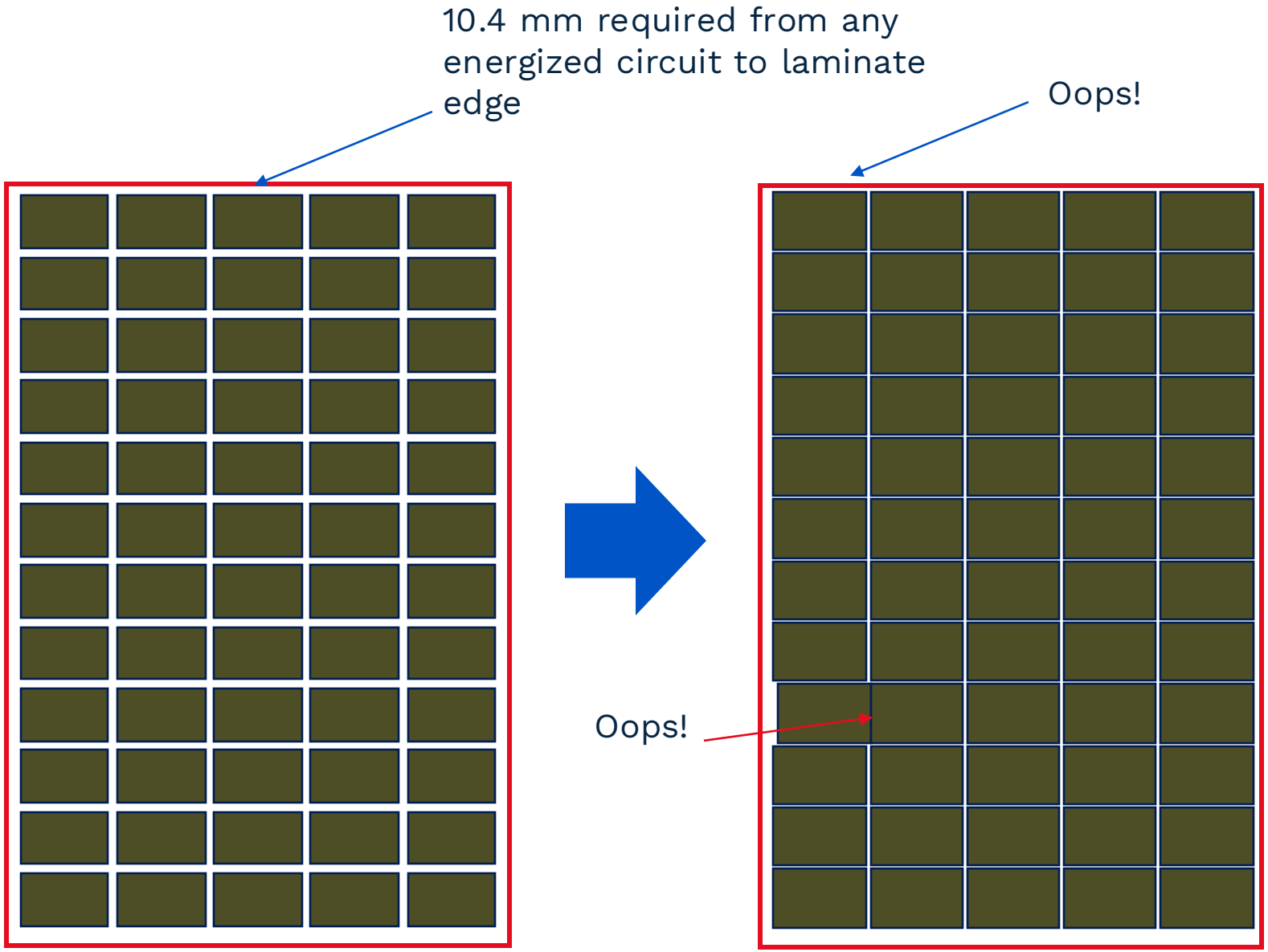
J. Phys. D: Appl. Phys. **2018**, 51, 123001

www.dmegcsolar.com

https://taiyangnews.info/technology/laplace-advances-topcon-with-poly-finger-designs-cost-reduction-strategies
https://taiyangnews.info/technology/dmegc-topcon-infinite-edge-passivation-agripv-anti-glare
https://doi.org/10.1016/j.proeng.2011.12.075

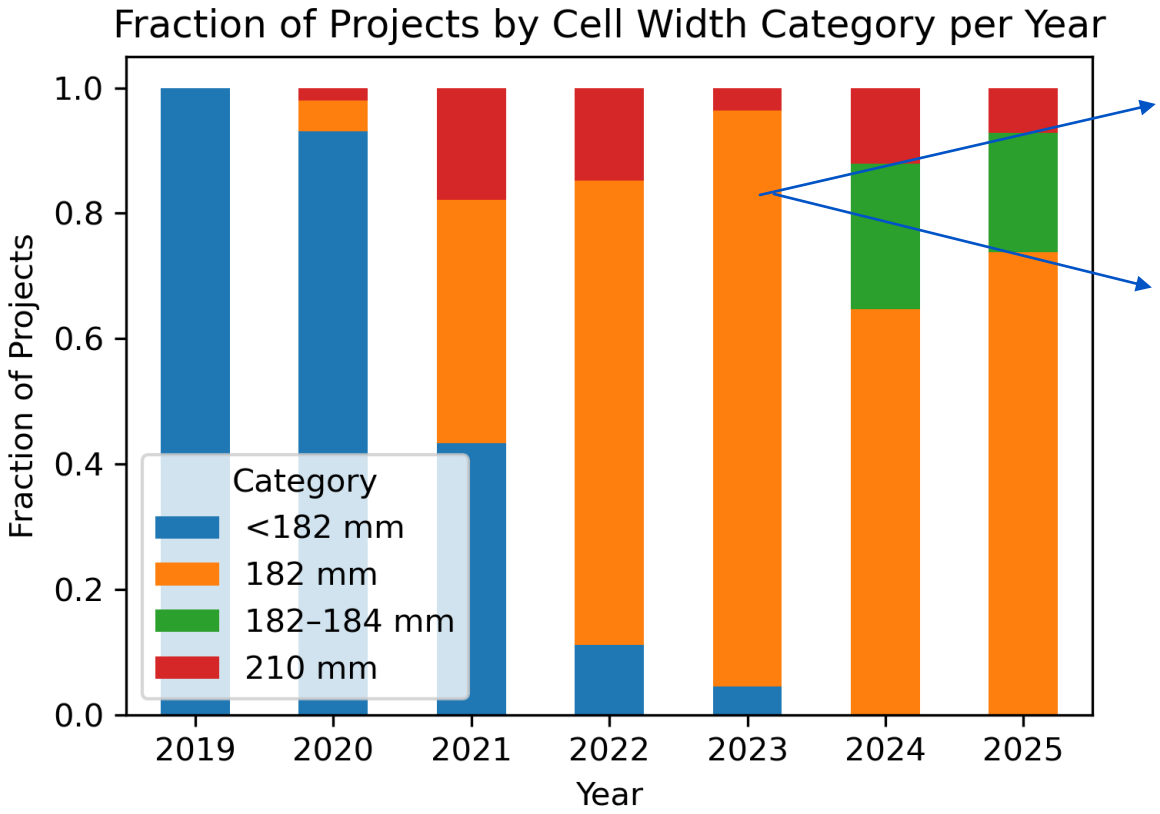
What's happening?

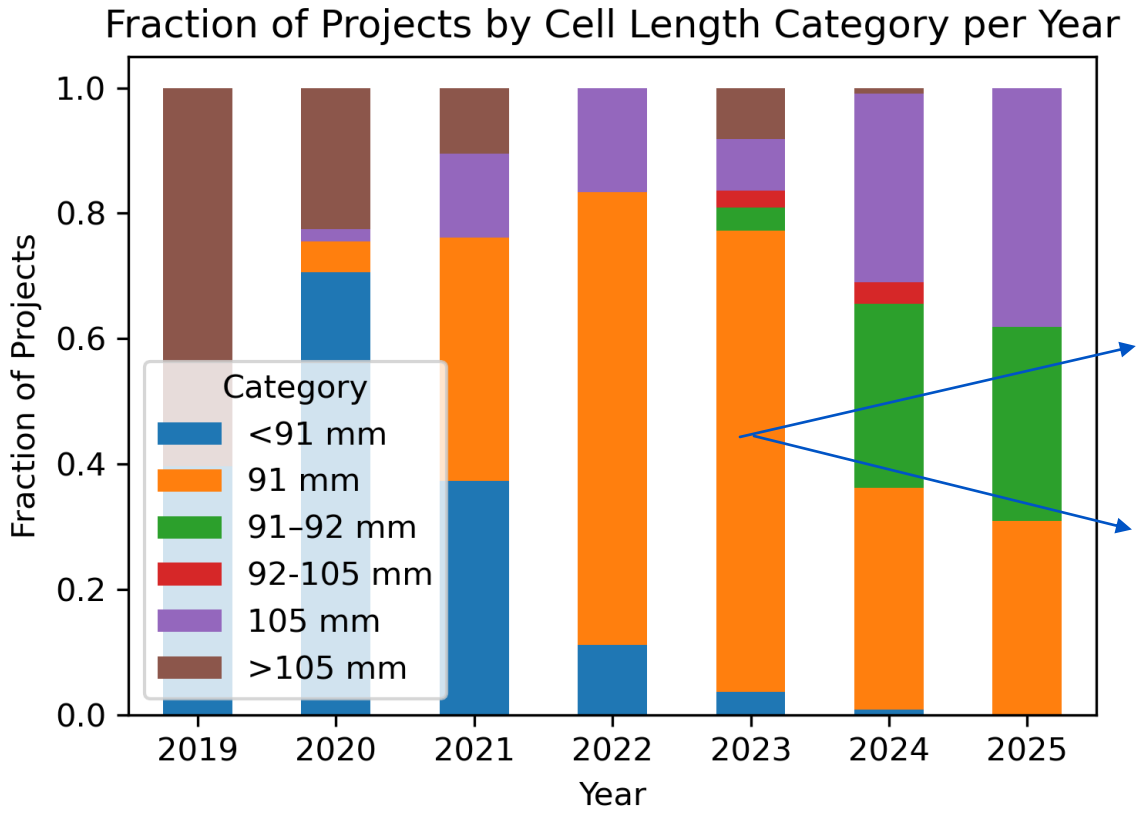
- Manufacturers are **increasing the size of the cells without changing laminate size** in order to increase module efficiency.
- **Technically possible to achieve the creepage distance, but some manufacturers do not have the ability to layout precisely enough**.
- IEC 61730-1: 10.4 mm required.



Squeeze just a little more cell in there!

- Data from PQP test samples.
- In the last few years, manufacturers are starting to push into the "slightly larger than 182x91 mm" cell size

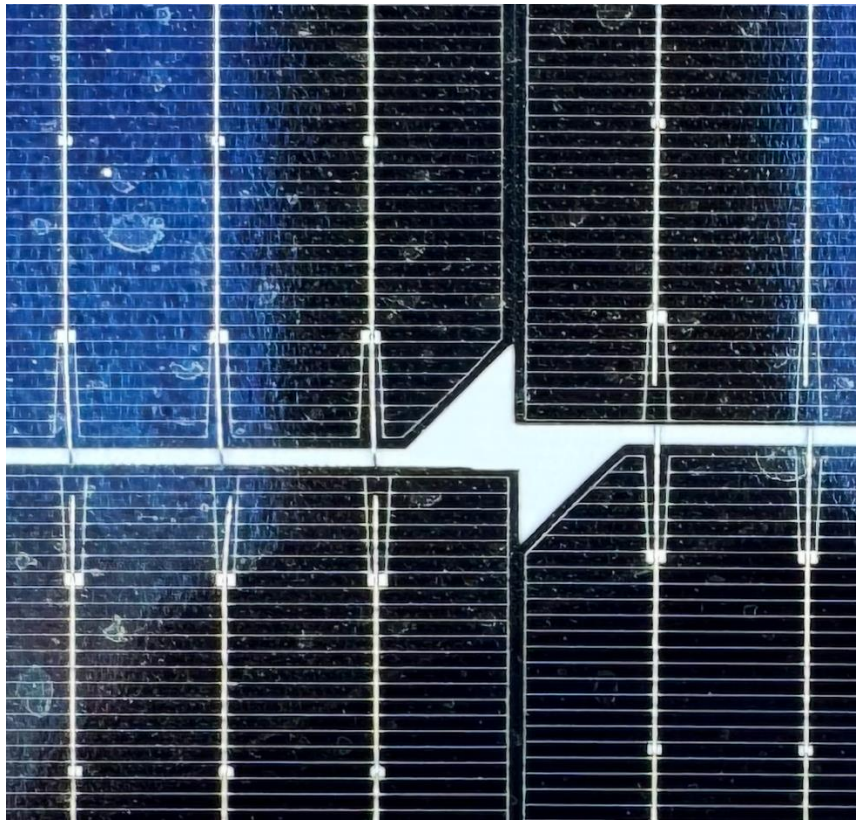




Layout issues exist

- We have observed major issues with modules not maintaining proper spacing between neighboring substrings in a module (1.0 mm required).
- Can lead to shorting, heating, glass breakage.

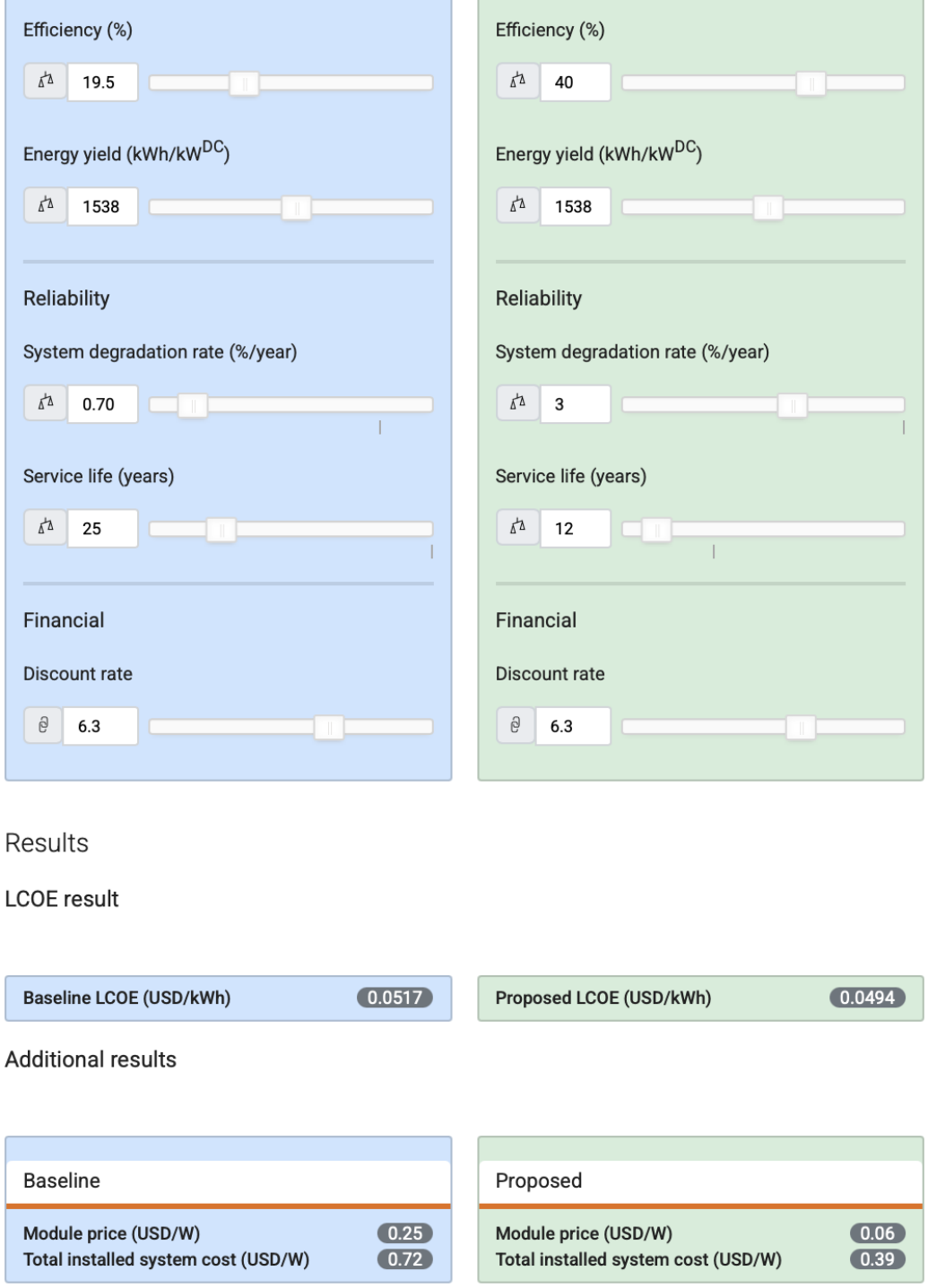
As module efficiency is squeezed higher by using bigger cells in the same size glass, layout issues are more likely.



Cells in neighboring substrings are shorted!

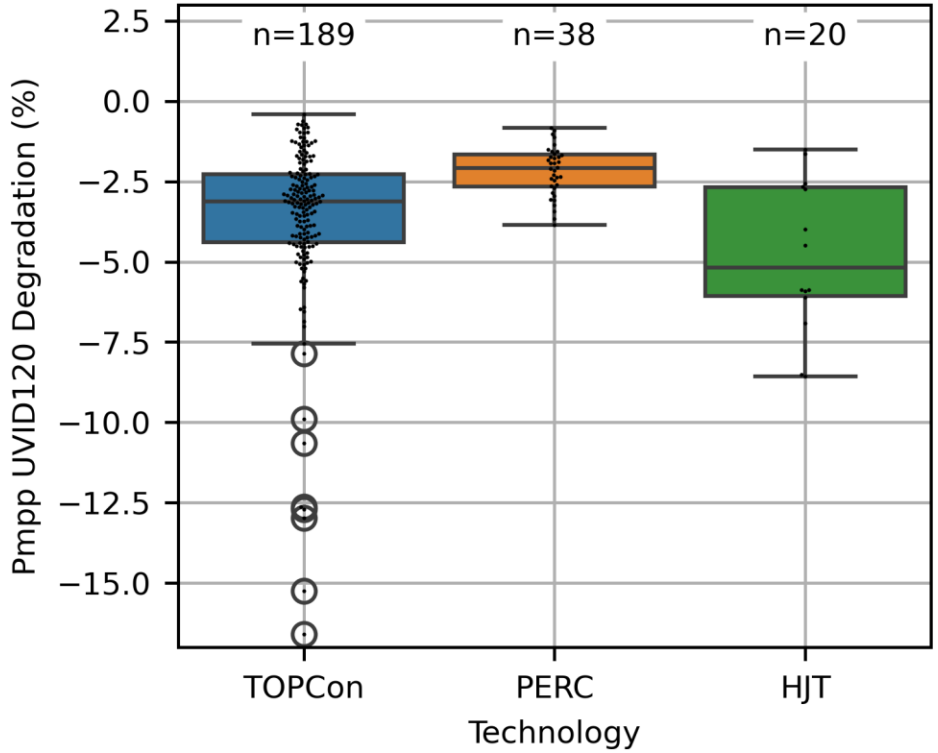
Perovskites are coming

- "Perovskites can't last 30 years, so they won't be deployed."
- A 40% efficient perovskite that degrades at 3%/yr and lasts 12 years still beats silicon for LCOE.
- We may want a 50 year module, the industry might want a 12 year module.



Conclusions

- **UVID**
  - UVID is still one of the major reliability problems for current PV modules.
  - Both in accelerated testing and field exposure.
  - UVID stability is improving.
- **Upcoming reliability challenges**
  - Slightly bigger cells.
  - Rear-side UVID sensitivity.
  - Perovskites.



Funding provided by the Durable Module Materials Consortium 2 (DuraMAT 2), an Energy Materials Network Consortium funded by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Solar Energy Technologies Office agreement number 38259. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government."