PV Reliability Workshop 2025

Accelerated UVID Testing and Comparison to Outdoor Testing

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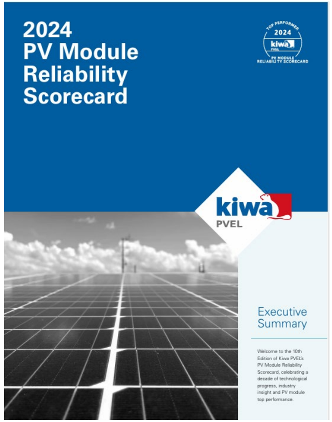
Mar 5, 2025

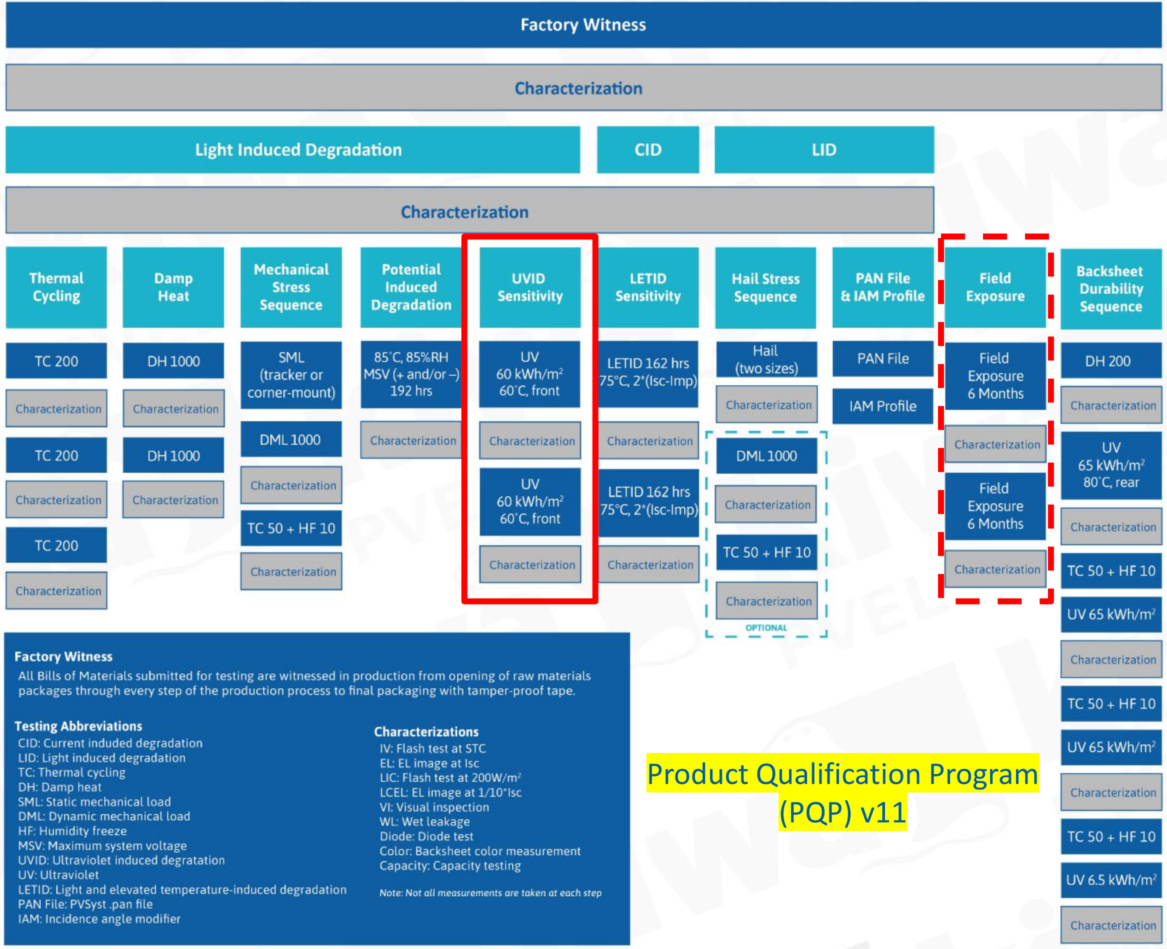
We Create Trust

About Kiwa PVEL

- Independent lab for PV Module **Performance and Reliability Testing.**
- Developed PQP test sequences.
- Releases PV Module Scorecard every year.
- Lists “Top Performer” for their superior test results.



TOP PERFORMER 2024 kiwa PVEL PV MODULE RELIABILITY SCORECARD



Product Qualification Program (PQP) v11

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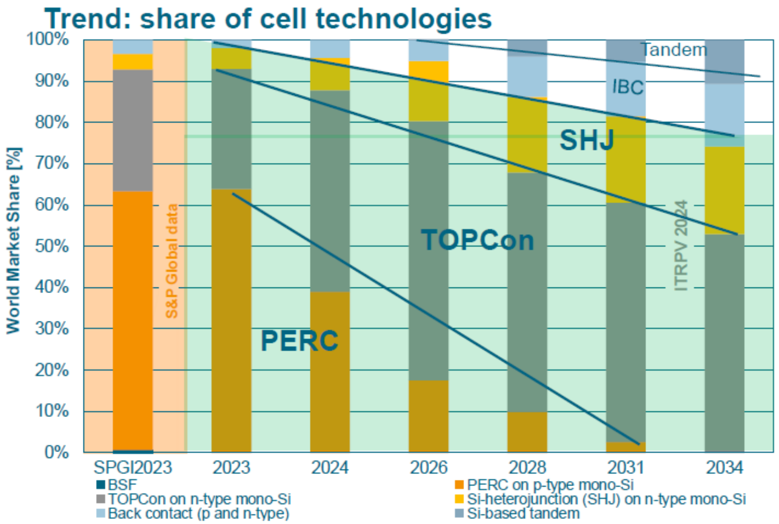
Solar PV Market Shift and UVID Concern

- Rapid adoption worldwide of n-type silicon cell topologies (TOPCon, HJT, xBC, …).
  - Higher efficiency due to better metallization scheme and improved passivation quality.
  - UV transparent encapsulants for current gain.

- Marketed with improved first year (-1%) and annual degradation rates (<-0.4%).
  - Kiwa PVEL's testing shows resiliency to LID and LETID.

- Higher **vulnerability to UV-induced degradation (UVID)** due to increased cell sensitivity to UV radiation (280-360 nm).
  - Negative impact on energy yield, reliability and bankability.



Source: ITRPV 2024

Kiwa PVEL's UVID Testing

- Testing **large-size industrial modules**.
- Outdoor preconditioning for LID stabilization.
- UV Testing with front-side exposure only.
- Exposure dose **120 kWh/m²** of UV (280-400 nm) when using metal-halide lamps or **55 kWh/m²** when using UV fluorescent lamps.
  - Equivalent to 1-2 years of outdoors, depending on location.
- Operating conditions: **module temperature 60°C ± 5°C**, under **short-circuit (SC) condition.**
  - *Historical testing results under UVF bulbs that contribute very little to the current generation.*
- Characterization include visual inspection, I-V at STC and low irradiance, high & low-current EL, wet leakage current test.

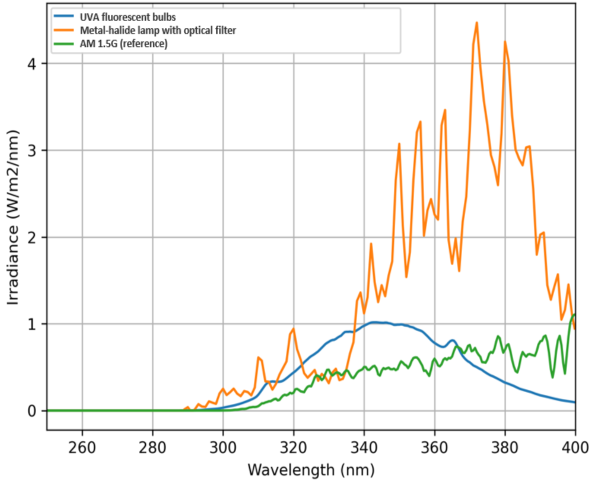
UVID Sensitivity

UV 60 kWh/m²
60°C front

Characterization

UV 60 kWh/m²
60°C front

Characterization



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New UV Chambers at Napa Lab

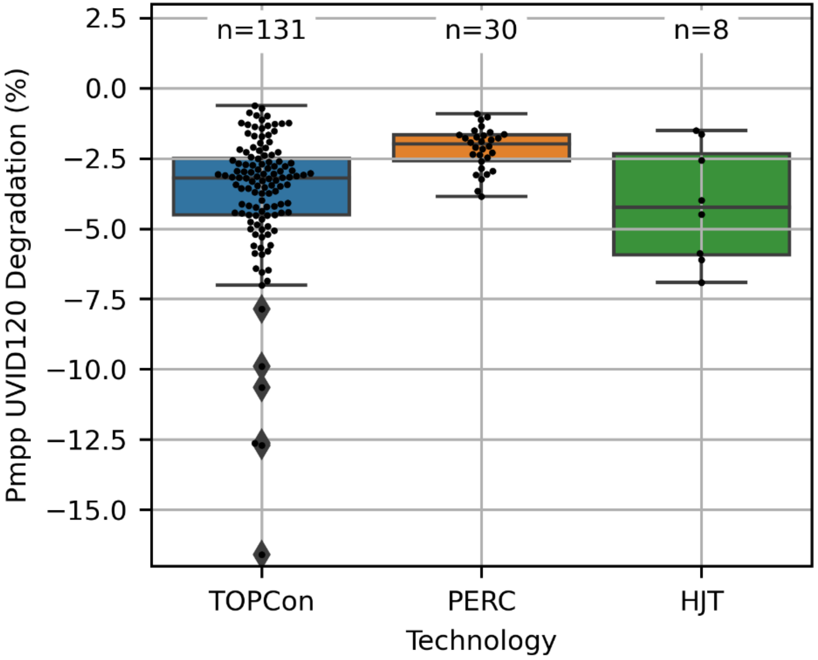
- Added two new UV chambers equipped with high-power UVF bulbs.
- **Higher UV intensity**, faster turnaround time.
- **In-house design and built from scratch.**
- Each chamber can accommodate **8 large-size modules (max. 2.7 m x 1.6 m)**.
- **Enhanced uniformity and control** over UV exposure conditions.
- **In-situ monitoring** of module temperature and UV irradiance at module test plane.

UVID Test Results: Variation with Cell Technology

- More than 85 BOMs evaluated, 2 modules per BOM.
  - 75% of them are TOPCon.

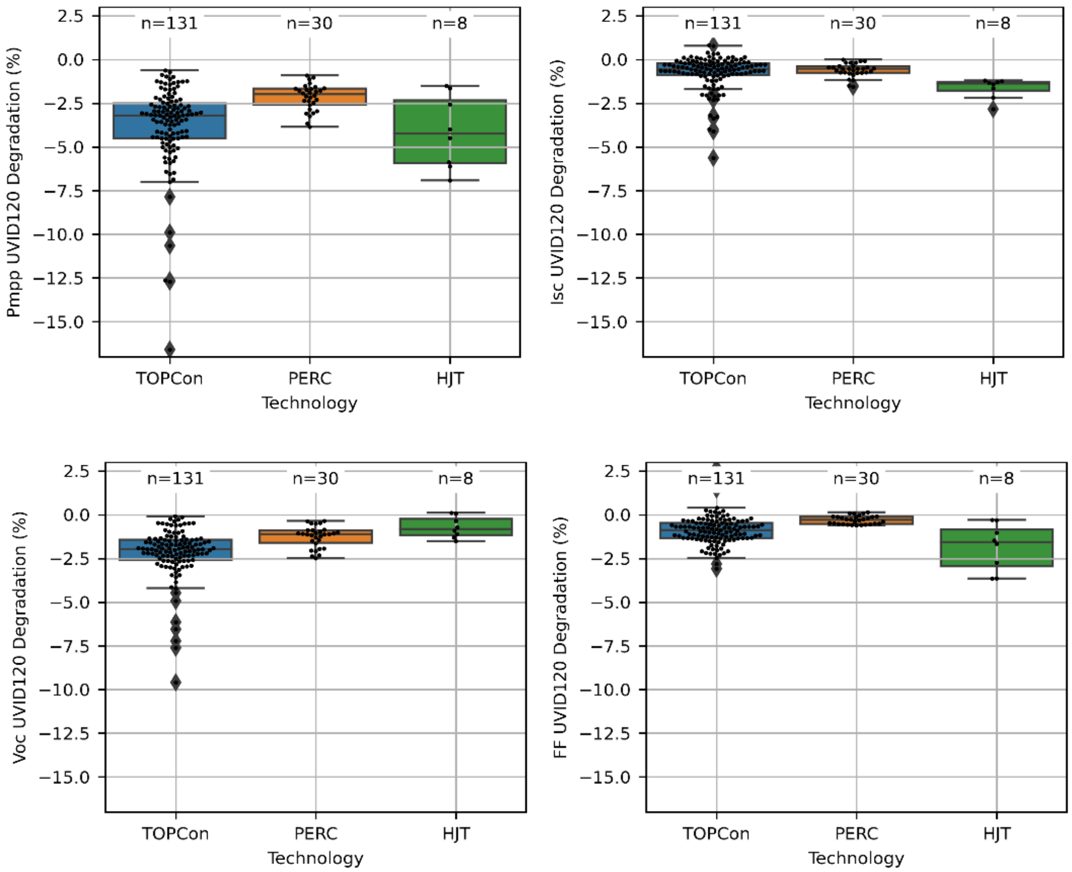
- Power degradation varies with cell technology.
  - TOPCon: range -0.6% to -17%, **median -3.1%**.
  - HJT: range -1.5 to -7%, **median -4.2%**, limited samples.
  - PERC: **median -2.2%.**

- UVID power loss is higher in n-type modules than p-type modules.
  - **N-type modules are more UVID-sensitive.**



Degradation in I-V Parameters

- TOPCon:
  - **Voc** is the most affected parameter → ***passivation loss***
  - Few BOMs showed greater Isc & FF losses → ***mismatch loss***
- HJT:
  - **Isc and FF losses** are significant → ***front TCO layer degradation***
  - Voc is fairly stable
- Different UVID failure mechanisms occurring concurrently in different cell types.



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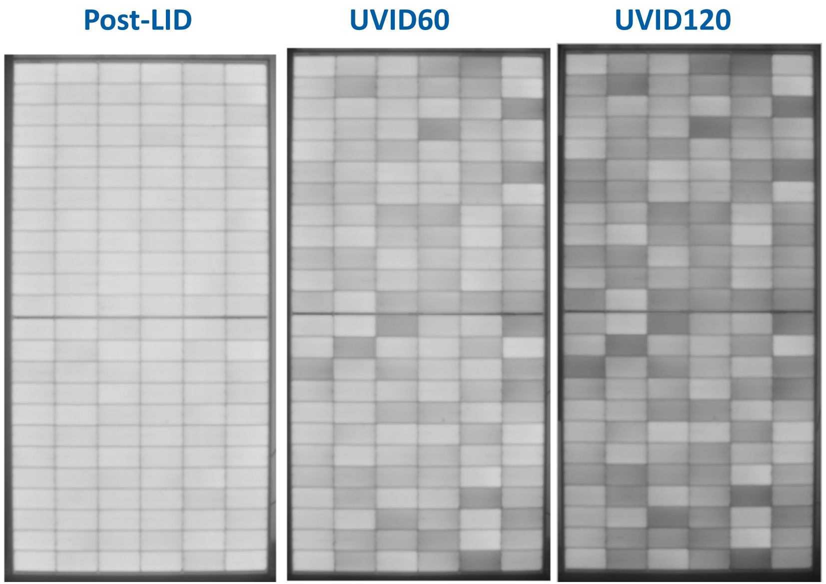
Degradation is Heterogeneous

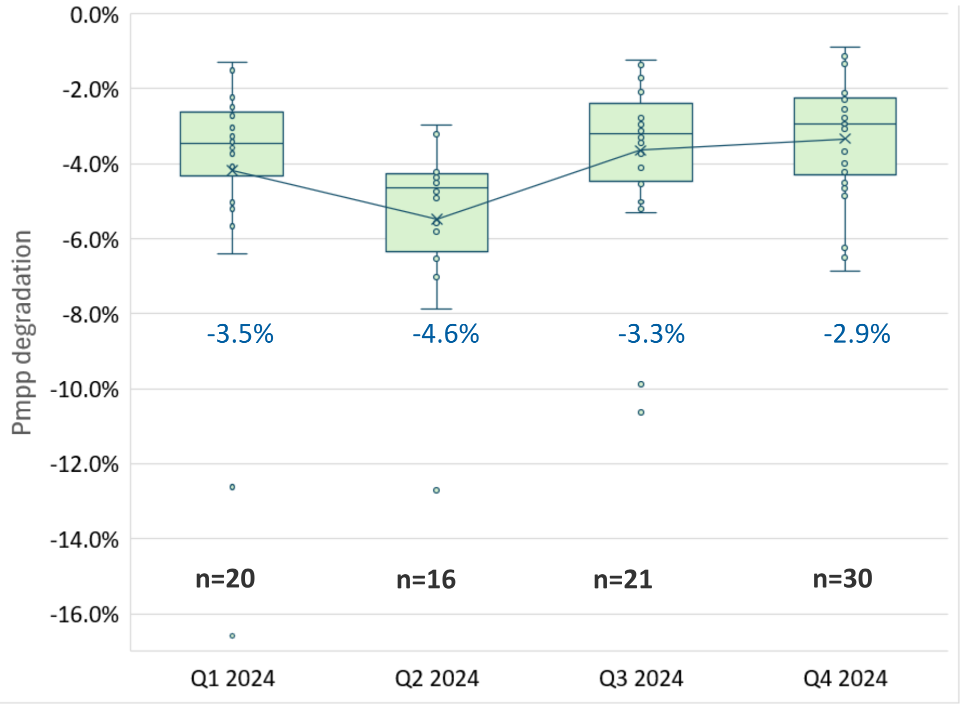
- Checkerboard pattern in EL images.
- Cells degrade **randomly** within the module, with no distinct pattern with position.
- Verified the pattern has **no correlation to the light non-uniformity** in the chambers.
- Possibly due to **variation in front cell passivation thickness** (critical parameter) during process quality control.

- Testing based on one-cell sample is not sufficient.
  - Test multiple cells
  - Perform batch testing



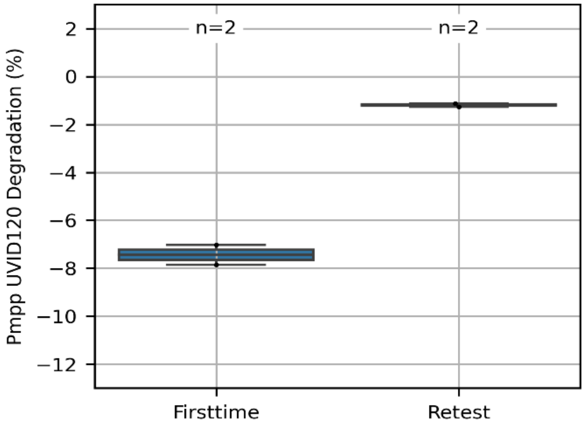
UVID Testing Timeline: Cell Processes Improvement

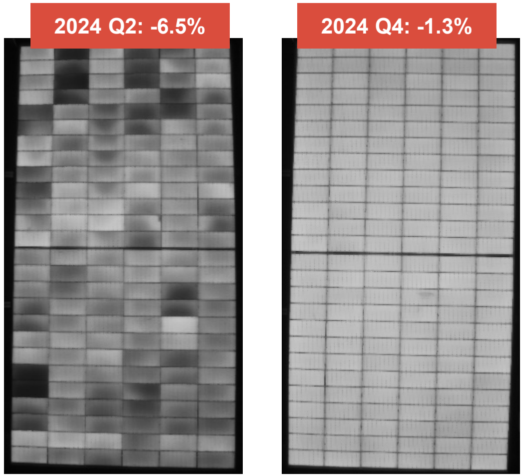
- Post-UVID120 power loss against samples production time (factory audit).
- Only results for TOPCon BOMs shown.
- Samples from Q1-Q2 showing worst results than Q3-Q4.
- **Less samples with excessive >-5% power loss in recent quarters.**
- Slight improvement in median power loss.
- Some manufacturers nailed it down (<-2% loss).



UVID Mitigation at Cell Level

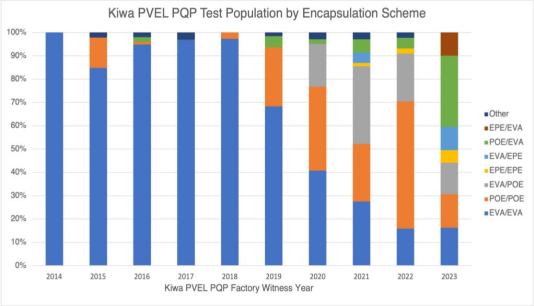
- Tier-1 cell manufacturer.
- First project tested in 2024 Q2, retest in 2024 Q4 with same BOM.
  - TOPCon cells in G//G construction.
  - EPE/EVA encapsulation scheme, standard recipe.
- From worse to best-in-class.
  - Original samples Pmax degradation -7.6% (average), strong checkerboard pattern.
  - Retest samples degraded by only-1.4% (average), no EL defects.
- Earlier discussion with manufacturer, pointed out to **front cell ARC/passivation layer process controls**.
- Two other projects with similar excellent results after recent UVID retests.

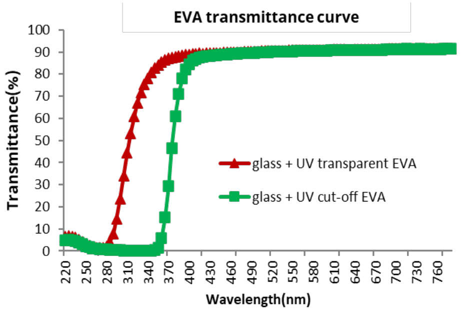


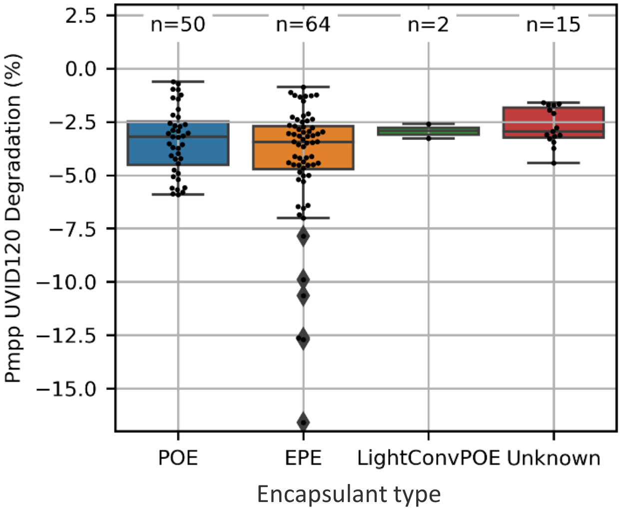


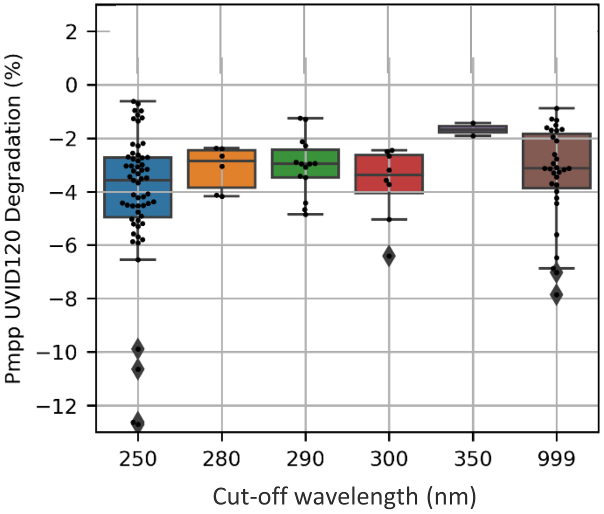
Role of Encapsulant

- TOPCon modules with varying encapsulant type.
- Base resin is not important, but **additives and UV cut-off wavelength are critical**.
  - Degradation increases with lower cut-off wavelength.
  - Higher degradation with UV transparent encapsulants.





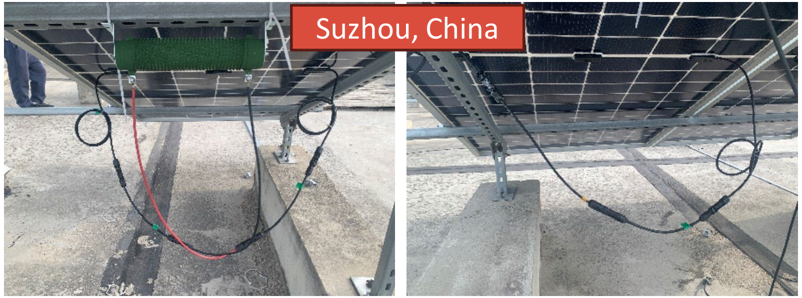




"999" refers to Unknown

Outdoor Testing

- Modules installed at different sites in the US and China under MPP and SC operating conditions.
  - Field exposed (FE) modules under PQP are under MPP and performance is evaluated after 6 month and 1-year.
  - Test modules installed in China are monitored on monthly basis.
- PQP FE projects are only shown.
- No separate LID is performed.
  - Power degradation is calculated with respect to intake characterization
- Modules are cleaned regularly to minimize the energy yield loss due to soiling.



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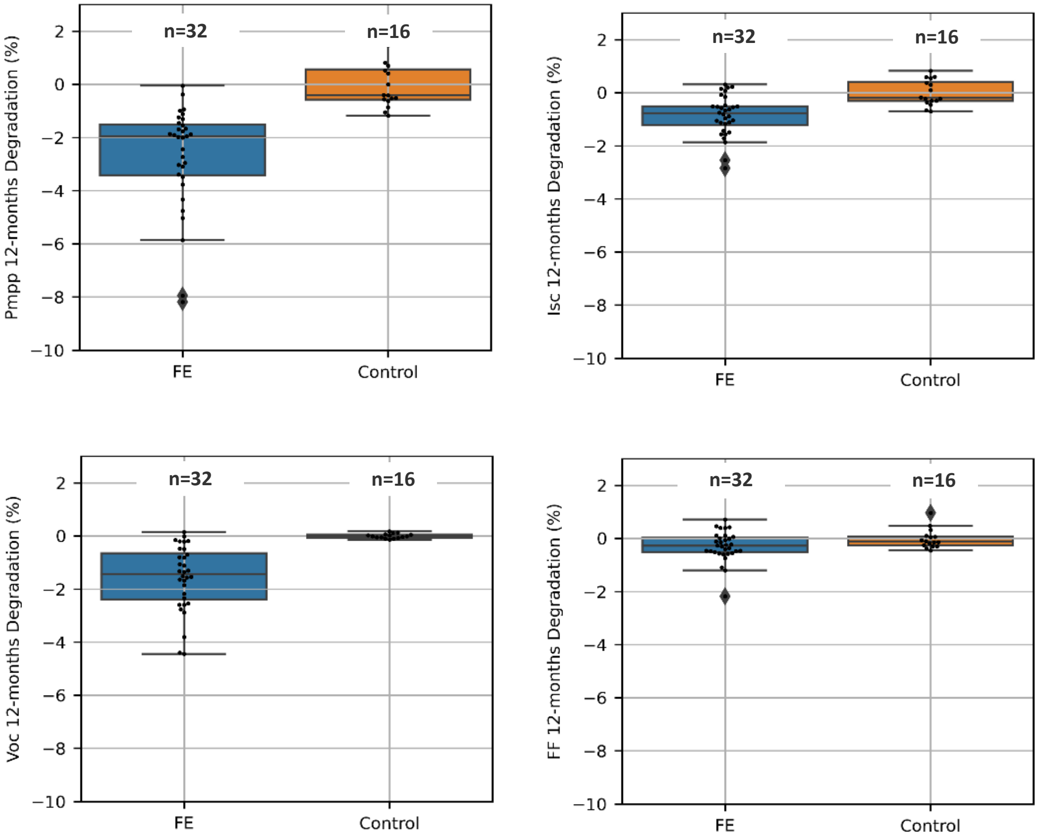
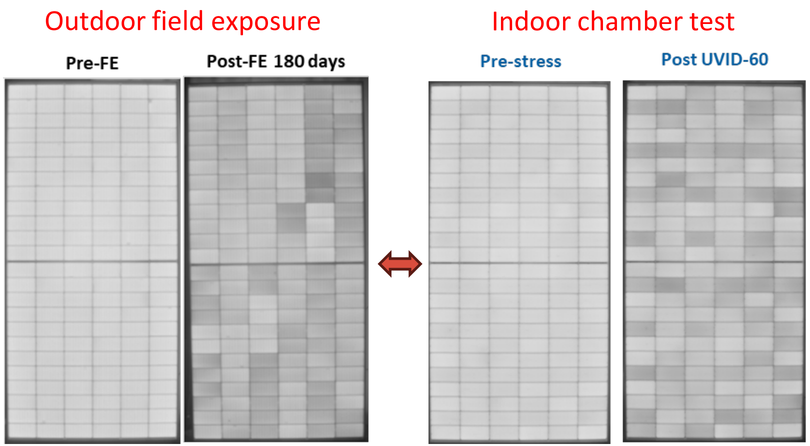
Field Degradation

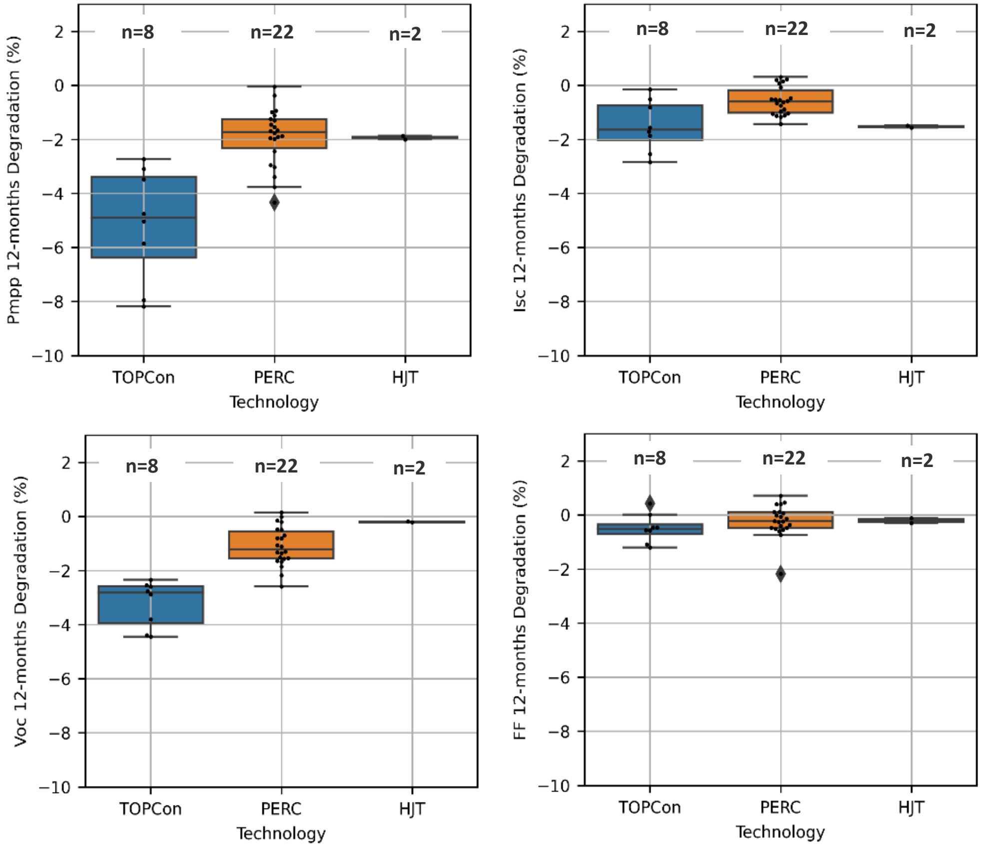
- PQP FE modules performance are evaluated for all technology modules.
- Total 16 BOMs. 2 test modules and 1 control per BOM.
- Significant degradation (**median -2%, highest -8%**) in fielded modules after 1 year of installation in Davis, CA.
  - **Mainly due to UVID**. Higher Voc loss in test modules. Isc and FF losses are lower.
  - Control modules exhibited stable performance.
  - LID and LETID combined Pmax loss is <-1% (refer PQP Scorecard 2024).



Comparison Field and Lab Testing

- Like chamber test, TOPCon FE modules degraded dramatically after 1-year.
- Similar checkerboard patten in FE module.
- **UVID is a real field-reliability problem.**

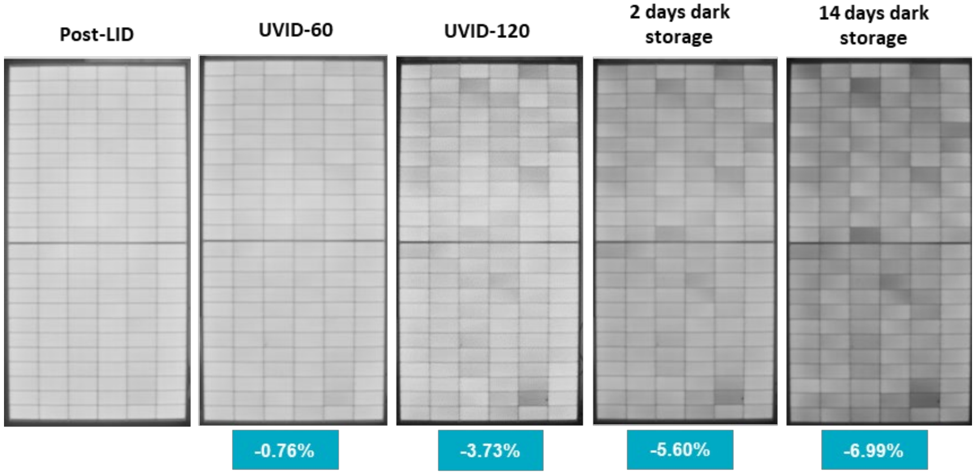




UVID/Dark Degradation and Metastability Issues

- TOPCon modules stored in dark after end of the test exhibited significant power degradation – **signs of metastability exist**.
- Experimented different recovery methods and results are very promising.

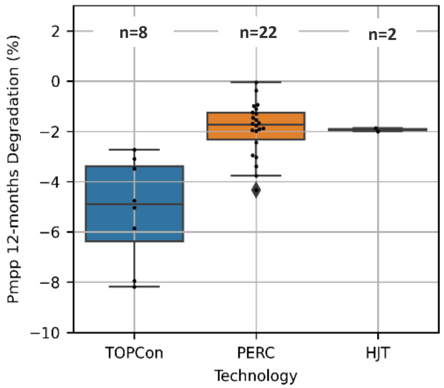
Step#	Pmp%	Voc%	Vmp%	Isc%	Imp%	FF%
Post-LID						
UVID-60	-0.76	-0.84	-1.02	0.60	0.31	-0.52
UVID-120	-3.73	-2.31	-3.24	-0.17	-0.45	-1.29
After 2 days dark storage	-5.60	-3.39	-4.98	-0.47	-0.60	-1.83
After 14 days dark storage	-6.99	-4.18	-5.66	-1.28	-1.42	-1.68



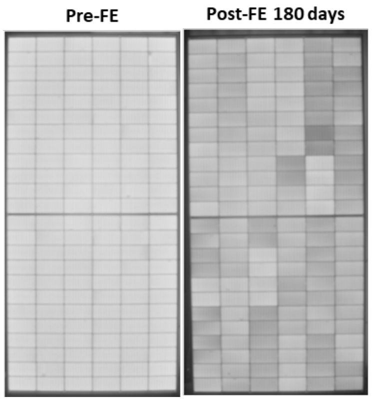
Todd's presentation: **Mar 6 (Thurs), 9.30 am**
UVID Initiates Metastability in the Dark:
How to Properly Measure n-Type Modules

Key Takeaways

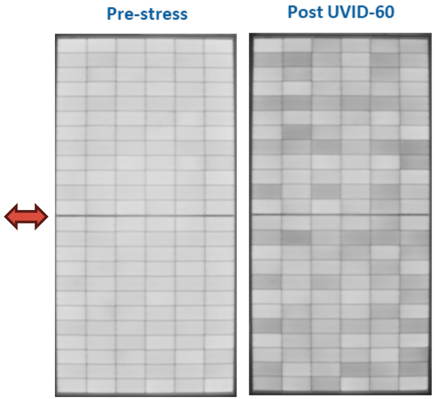
- UVID is a big **reliability challenge for n-type modules**, which exists in the field as well and significantly increase risk of exceeding first year degradation (<-1%).
- Kiwa PVEL has enhanced UV test capacity, please contact us if you'd like to test your modules.
- Recent UVID testing showed lesser modules are exceeding power loss >-5%.
- Some manufacturers have understood on how to control the UVID at cell level.

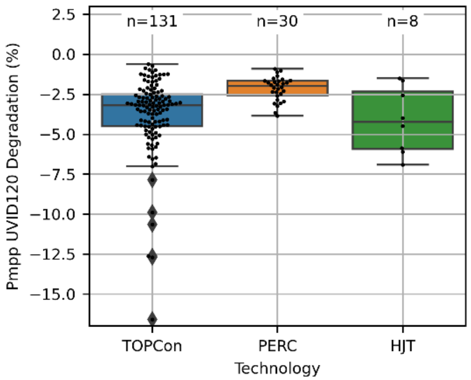


Outdoor field exposure



Indoor chamber test





Thank you!

- *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.*

- Kiwa group partners
  - PVEL test facilities in the US and China
  - PI Berlin for Factory audit

- For collaboration and any queries, please contact us.

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