



UV-Induced Degradation in TOPCon Modules:

Linking Accelerated Testing and Field Evidence

Todd Karin, Archana Sinha, Jean-Nicolas Jaubert, (Kiwa PVEL)
Dana B. Kern (NLR)

9/14/2026
2026 EUPVSEC
9/14/2026

kiwa

creating trust, *driving progress*

Talk Tomorrow on PQP failures.

Kiwa PVEL

- Independent lab for PV Module **Performance and Reliability Testing.**
- Headquarter test lab at Napa, US and a sister company at Suzhou, China.
- Known for **PQP test sequences**, which gets updated every 2 years.

See more details at kiwa.com/pvel

12+

Years of experience

700+

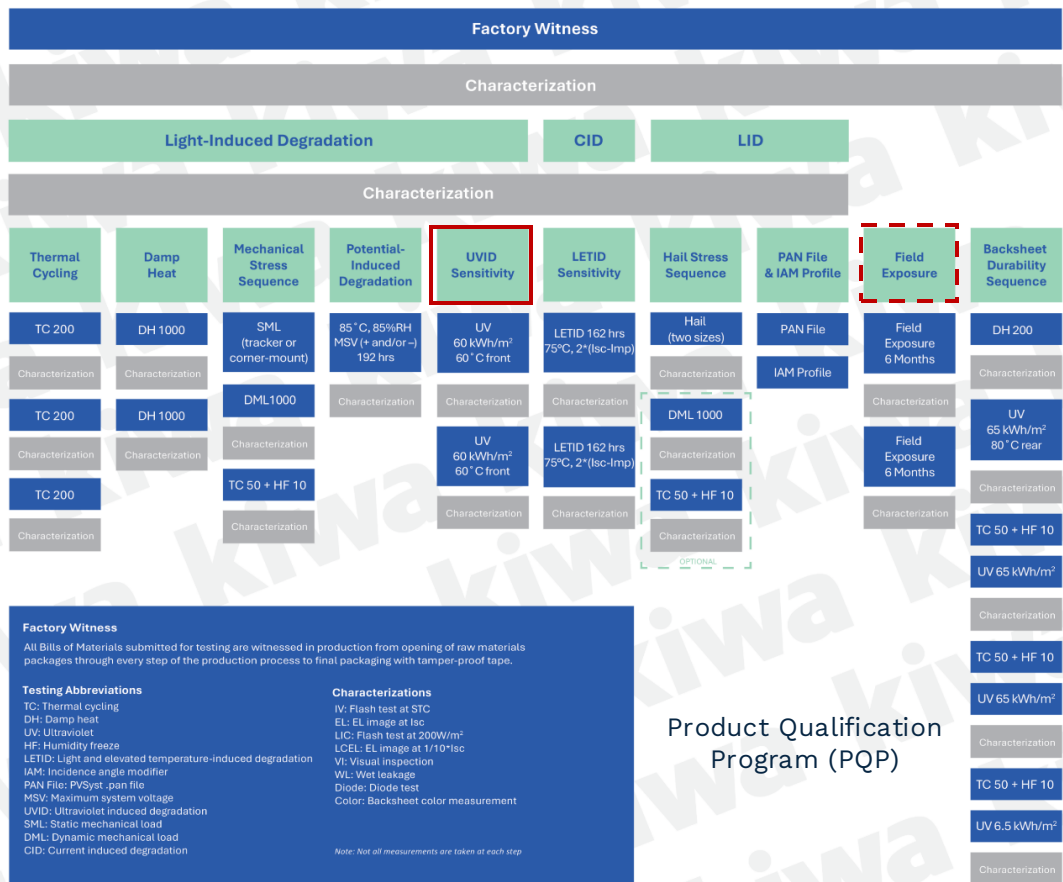
Bills of materials tested in the lab

400+

Downstream partners

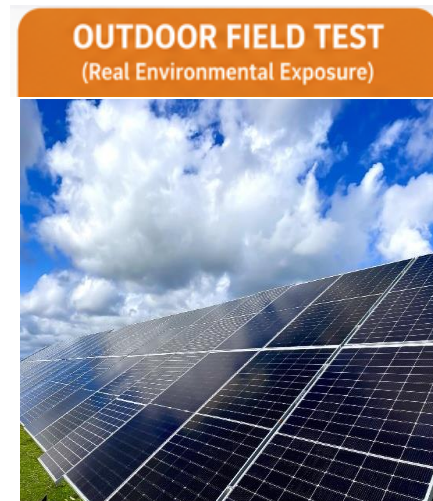
Our mission is to support the worldwide solar and energy storage buyer community by generating data that accelerates adoption of solar technology.

kiwa



Product Qualification Program (PQP)

Agenda



**UVID Mitigation
Strategies**

**UVID
Metastability and
Stabilization**

Why UVID?

- High-interest topic within the PV reliability community as newer cell architectures and module materials are deployed at scale
- Degradation occurs at cell level and adversely impacts the system performance and warranty in the field.

this webinar is powered by Quantified Energy

pv magazine webinars

25 March 2026
8:00 am – 9:00 am | PDT, Los Angeles
11:00 am – 12:00 pm | EDT, New York City
4:00 pm – 5:00 pm | CET, Berlin, Paris

UVID: Risks, detection, and impact on solar projects

Mark Hutchins
Magazine Director
pv magazine

Yong Sheng Khoo
Chief Operating Officer & Co-founder
Quantified Energy

Johnson Wong
Chief Scientist
Quantified Energy

Tristan Erion-Lorico
VP of Sales & Marketing
Kiwa PVEL

Solving the UV problem of n-type solar

Laboratory testing has revealed that some negatively-doped, “n-type” tunnel oxide passivated contact (TOPCon) and heterojunction (HJT) solar modules are susceptible to ultraviolet (UV) light-related damage and degradation. That could mean trouble down the line, if modules in the field begin to show UV-related performance loss. Manufacturers are implementing solutions at cell and module level.

OCTOBER 21, 2024 MARK HUTCHINS

TECHNOLOGY TECHNOLOGY AND R&D WORLD

[Solving the UV problem of n-type solar – pv magazine USA](#)

New research warns of unexpected UV-induced degradation in TOPCon solar cells from invisible light

Researchers from UNSW have found that invisible light accelerates UV-induced degradation in TOPCon solar cells, producing the same degradation effects as visible light but at a much faster rate. This can lead to significant open-circuit voltage losses and reduce cell efficiency.

AUGUST 11, 2025 EMILIANO BELLINI

MODULES & UPSTREAM MANUFACTURING TECHNOLOGY AND R&D AUSTRALIA

[New research warns of unexpected UV-induced degradation in TOPCon solar cells from invisible light – pv magazine International](#)

NREL researchers quantify UV-induced degradation levels in TOPCon solar cells

Researchers at NREL found that UV exposure can cause significant, partly non-recoverable degradation in TOPCon solar cells, with strong cell-to-cell and intra-cell variability linked to passivation and processing inconsistencies. While some UV-related losses recover quickly under light and are unlikely to affect field performance, the findings highlight gaps in current qualification tests and the need for improved UV aging standards.

FEBRUARY 18, 2026 EMILIANO BELLINI

TECHNOLOGY TECHNOLOGY AND R&D UNITED STATES

[NREL researchers quantify UV-induced degradation levels in TOPCon solar cells – pv magazine USA](#)

PROGRESS IN PHOTOVOLTAICS

RESEARCH ARTICLE | [Open Access](#) | [DOI](#)

UV-induced degradation of high-efficiency silicon PV modules with different cell architectures

[Correction\(s\) for this article](#)

Archana Sinha, Jiadong Qian, Stephanie L. Moffitt, Katherine Hurst, Kent Terwilliger, David C. Miller, Laura T. Schelhas, Peter Hacke

First published: 07 July 2022 | <https://doi.org/10.1002/pip.3606> | [VIEW METRICS](#)

PROGRESS IN PHOTOVOLTAICS

RESEARCH ARTICLE

UV-Induced Degradation and Associated Metastability in TOPCon Photovoltaic Modules: Understanding Kinetics and Cell Variance

Dana B. Kern, Rebecca Wai, Kent Terwilliger, Steve Johnston

First published: 08 January 2026 | <https://doi.org/10.1002/pip.70067> | [VIEW METRICS](#)



Solar Energy Materials and Solar Cells
Volume 294, January 2026, 113895



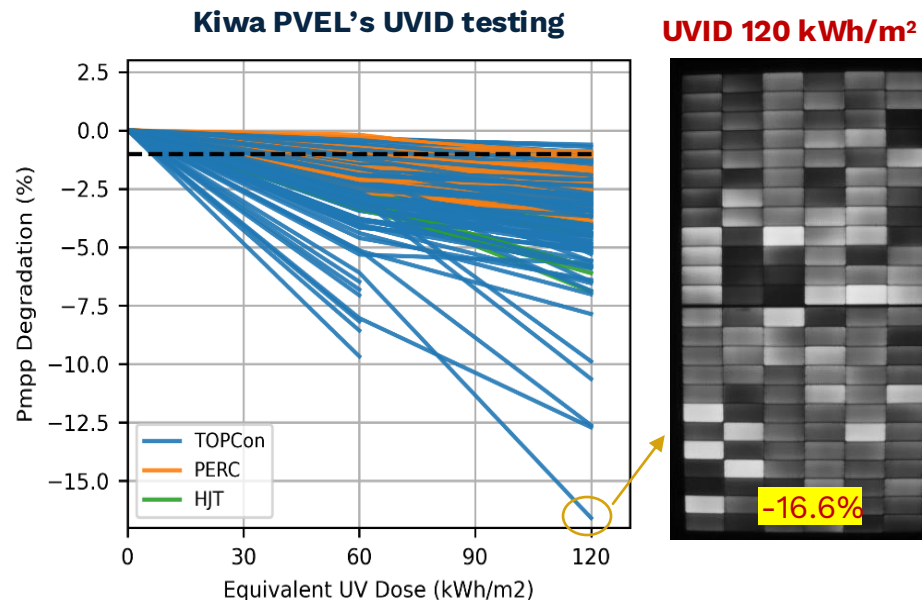
UV-induced degradation in TOPCon solar cells: Hydrogen dynamics and impact of UV wavelength

Muhammad Umair Khan^a, Chandany Sen^a, Michael Pollard^a, Ting Huang^b, Munan Gao^b, Ruirui Lv^b, Yuanjie Yu^b, Xinyuan Wu^a, Haoran Wang^a, Xutao Wang^a, Bram Hoex^a

[DOI](#)

UVID Concern for N-Type Modules

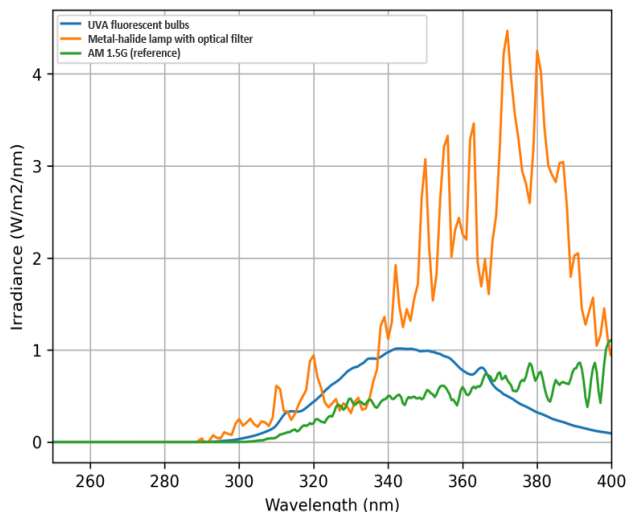
- Rapid shift to n-type cells.
- **TOPCon is the predominant technology.**
 - Higher module efficiency compared to PERC (~9% relative)
 - Initial power gain best with UV transparent encapsulants.
 - Marketed with improved first year (1%) and annual degradation rates (<0.4%/yr).
 - Resilience to LID and LETID. Combined loss <1%.
- N-type has higher **vulnerability to UVID**
 - TOPCon and HJT modules showed a broad range of UV susceptibility (0.4% to 16.6% deg)
 - Variability in bill of materials, cell architecture, and process non-uniformities.
 - UVID can wipe out advantages of PERC over TOPCon for worst performing TOPCon modules.



TOPCon modules with poor UV stability can underperform PERC!

Kiwa PVEL's UVID Testing

- UV Testing with **front-side exposure**.
- UV exposure dose **120 kWh/m²** of UV (280-400 nm) when using **metal-halide lamps (PI China)** or **55 kWh/m²** when using UV fluorescent lamps (Napa).
- Module temperature 60°C ± 5°C, under **short-circuit condition**.



UVID
Sensitivity

UV 60 kWh/m²
60°C front

Characterization

UV 60 kWh/m²
60°C front

Characterization



UVF chamber at Napa, CA



Indoor UVID Testing

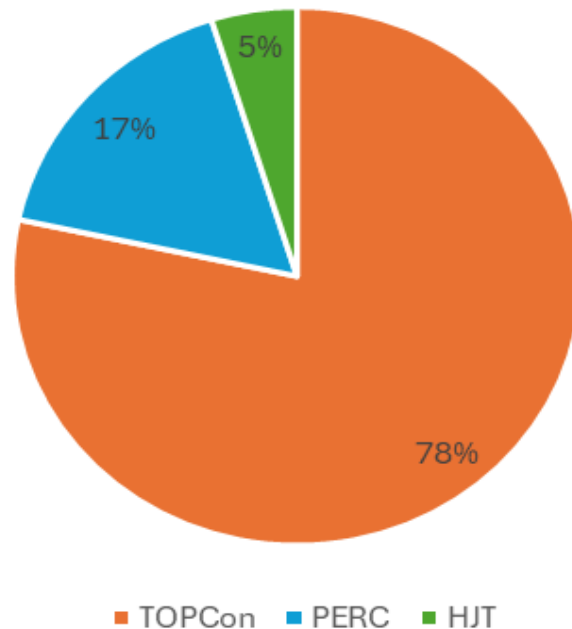
Kiwa PVEL

kiwa

creating trust, *driving progress*

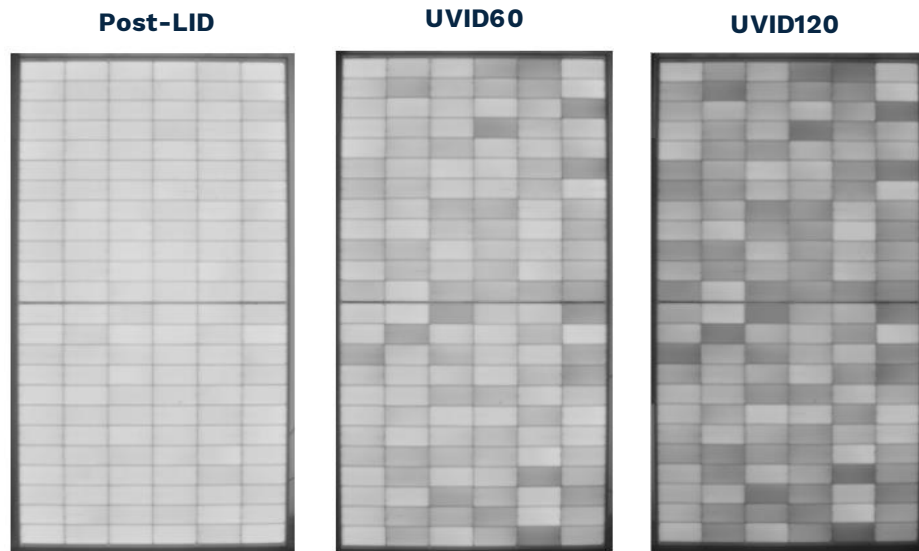
Test Population

- Largest “public” UVID dataset (2024-2026):
 - Total **370 modules**. (millions of \$).
 - All industrial modules, manufactured at different locations globally (China, India, US...).
 - TOPCon constitutes 78% of test population.
- General BOM trends:
 - Most of them are bifacial G/G modules
 - Encapsulants are a mix bag – EVA, POE, EPE, UV down conversion
- xBC and CdTe technology modules also tested but not included in this study.



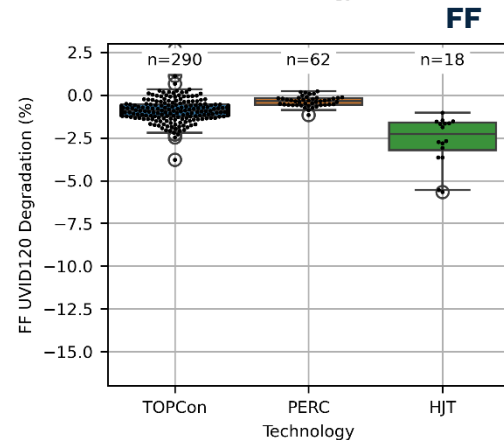
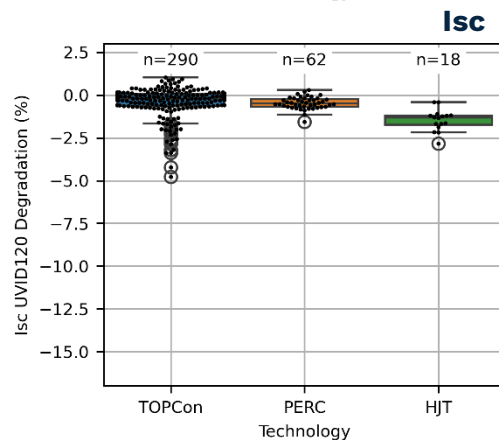
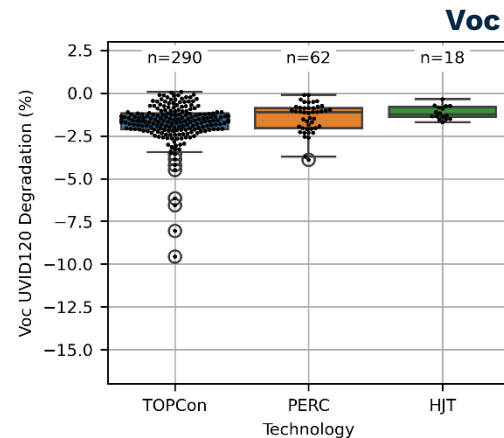
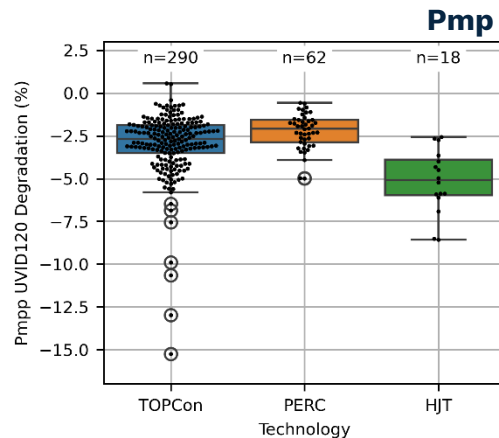
UVID Test Results

- Characteristic **“Checkerboard” pattern** in EL images.
 - More pronounced with prolonged UV exposure.
 - Degradation is not uniform across the cells.
 - Position-independent (unlike PID-s).
- **UV susceptibility can vary from cell to cell within the same module.**
- Testing based on a few cells is not sufficient.
 - Test multiple cells or modules from different batches.



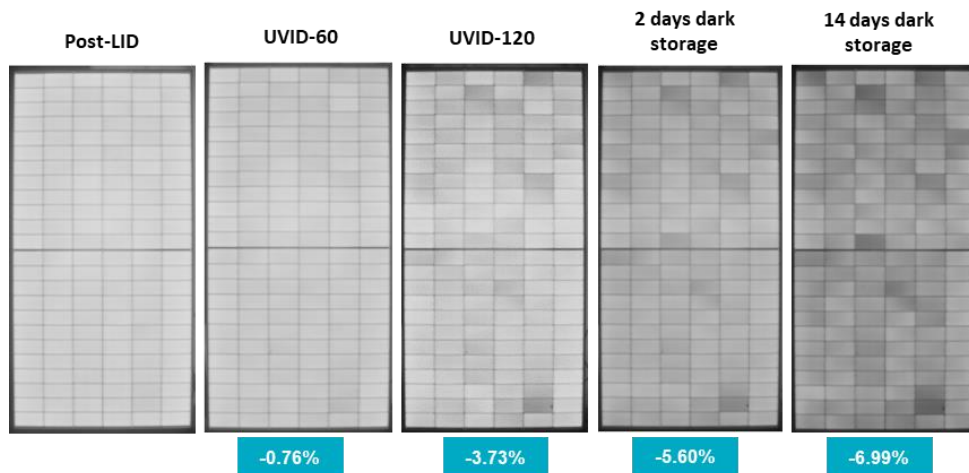
UVID Degradation Pathways

- UVID mechanisms vary by cell types.
 - TOPCon:** 0.4-16.6% deg, median 3.0%
 - Voc most affected** → cell passivation degradation
 - Greater Isc & FF losses in few BOMs → mismatch loss
 - HJT:** 1.5-8.6% deg, median 5.2% (limited sample size)
 - Isc and FF losses are significant** → front TCO/a-Si interface degradation
 - Voc is fairly stable
 - PERC:** lower degradation, median 2.1%



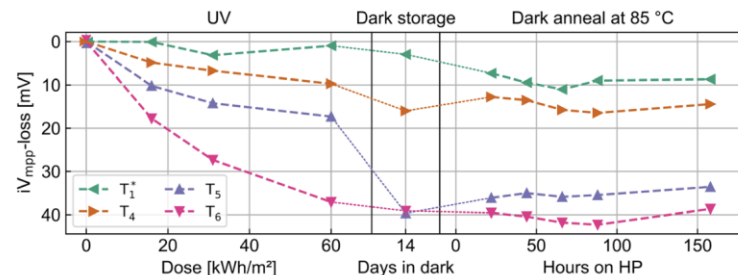
Reversible Dark Storage Degradation

- **Signs of metastability** observed in the modules following UV exposure when stored in the dark.
- Significant power loss and pronounced checkerboard pattern.
- **Higher degradation with longer dark storage period.**
- Maximum degradation up to 1%/day.

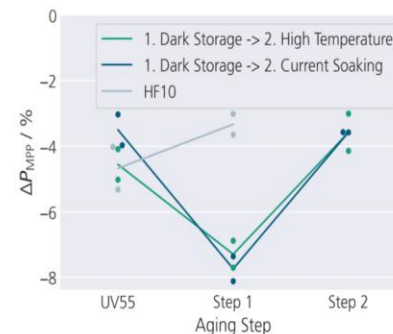


Other's work

[1] Cell: 0.5%-3.0% degradation in dark



[2] TOPCon modules degraded under dark storage post UV test.



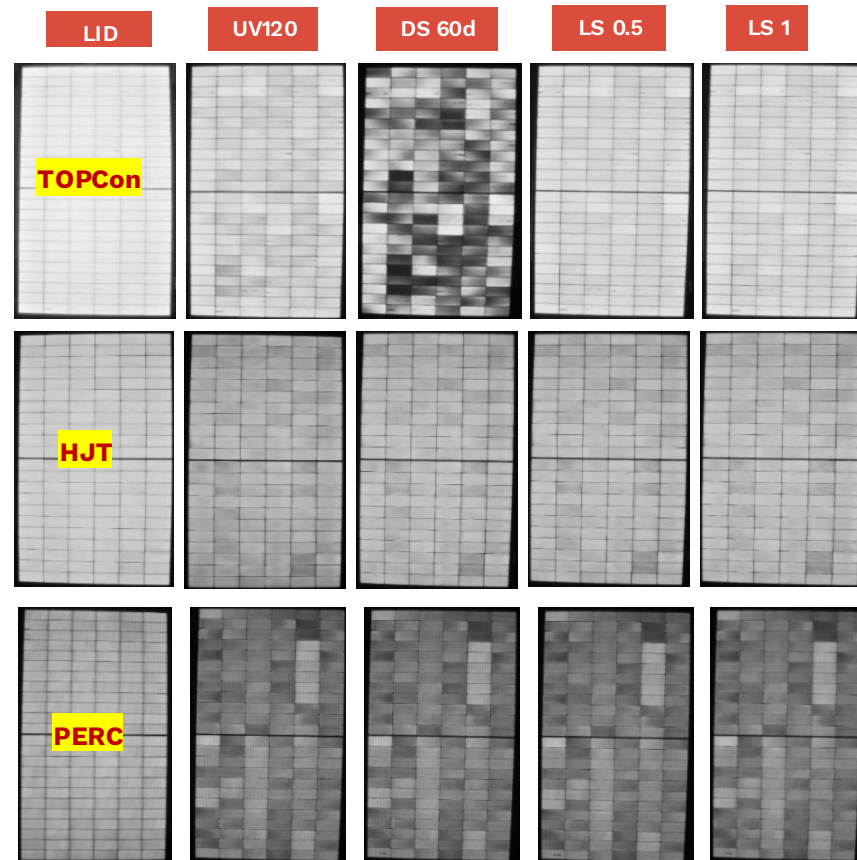
[1] Thome et. al. Solar RRL (2024), 8, 2400628

[2] Gebhardt, P., Kräling, (2024), Prog Photovolt Res Appl

Dark Storage Degradation and Stabilization

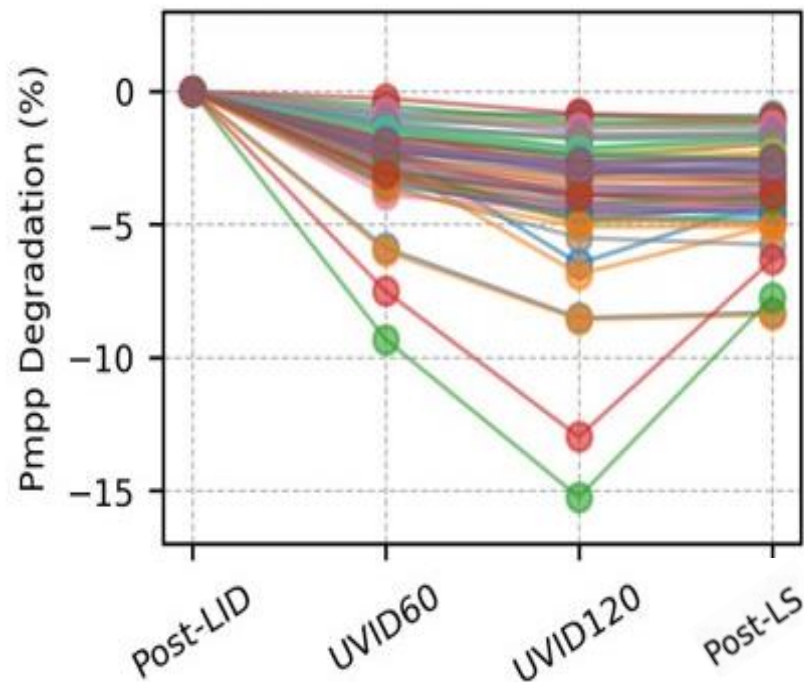
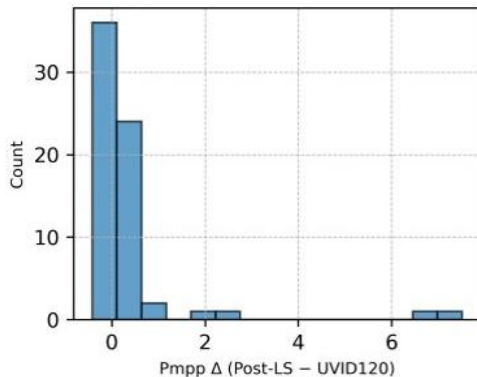
- Dark storage degradation is partially or fully recoverable via full-spectrum light soak.
- UV induced degradation isn't recovered.**
- In general,
 - TOPCon (extensive) - Fast and effective recovery.
 - HJT (moderate) - Slower recovery.
 - PERC (minimal) - No metastability.

Pmax	Bad PERC	Good PERC	Bad TOPCon	Good TOPCon	HJT
LID	0.0%	0.0%	0.4%	-0.1%	0.1%
UVID120	-3.0%	-1.9%	-5.6%	-1.4%	-4.5%
Dark Storage	-3.8%	-2.3%	-12.3%	-2.6%	-6.3%
LS 0.5kWh/m ²	-3.8%	-2.4%	-5.7%	-2.4%	-6.0%
LS 1kWh/m ²	-3.7%	-2.3%	-5.6%	-2.3%	-5.5%



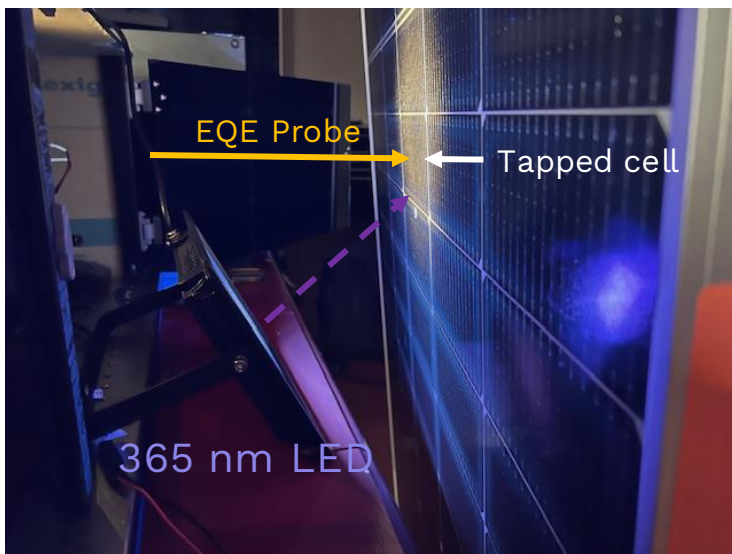
Light Soak Stabilization

- Kiwa PVEL implemented a LS stabilization step post-UVID120 (via 0.5–1 kWh/m² of full spectrum light soak) if more than 48 hours passed since test completion.
- **For UVID-sensitive samples, light soak is crucial to get accurate results.**
- Many test samples are not affected by LS (change is <0.4%), but some are very affected.



EQE change during recovery

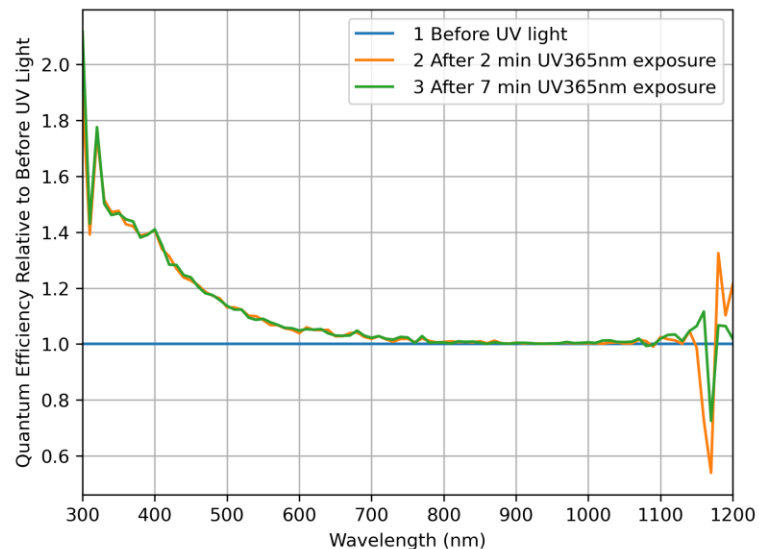
- TOPCon module experienced UVID followed by several months of dark storage.
- Acquired EQE before and after a 2 minutes dose from UV LED at 365 nm.



- Change in EQE during recovery shows power gain is greatest in the blue/UV region.

Clear evidence that:

The dark-storage defect causes front-side passivation loss



UV LED (100 W, 365 nm)





Correlation of Indoor and Outdoor Testing

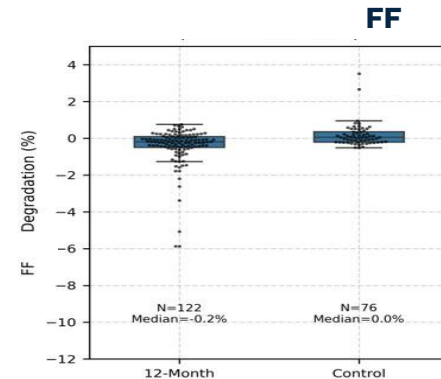
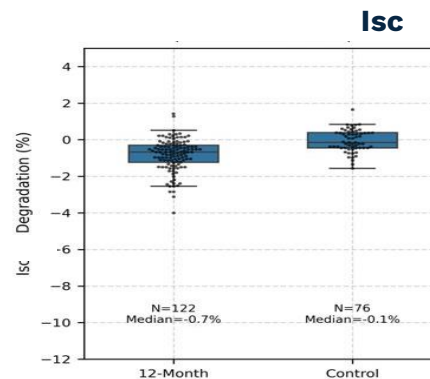
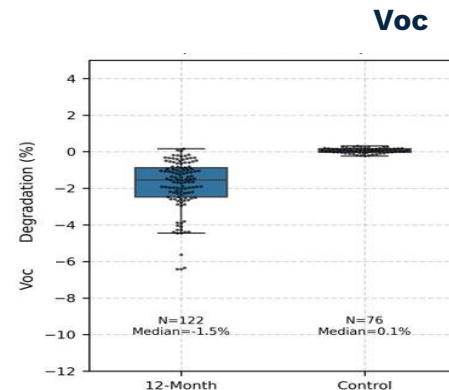
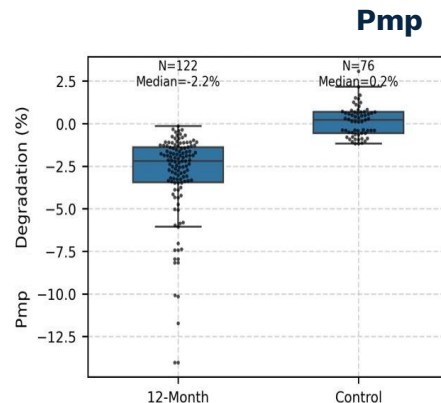
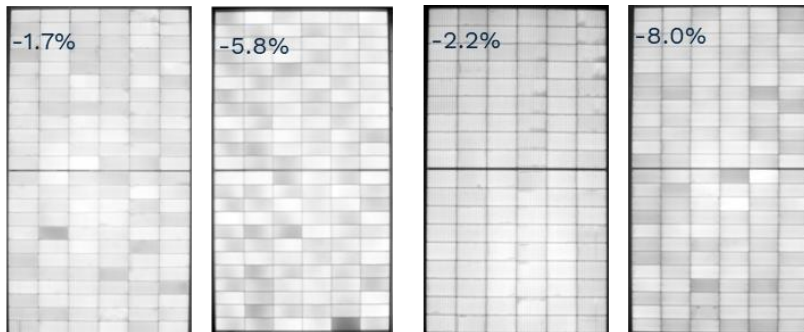
Kiwa PVEL

kiwa

creating trust, *driving progress*

Field Exposure Testing & UVID Signatures

- 1-year outdoor exposure in Davis, CA.
 - Modules installed in 2023-2025 period.
 - Control modules exhibited stable performance.
- Significant Pmp degradation in field-exposed (FE) modules - median of 2.2%
 - Driven by Voc** and some Isc losses, while FF is stable.
 - Combined LID and LETID Pmp loss <1%.
 - UVID checkerboard pattern is visible in EL images.**

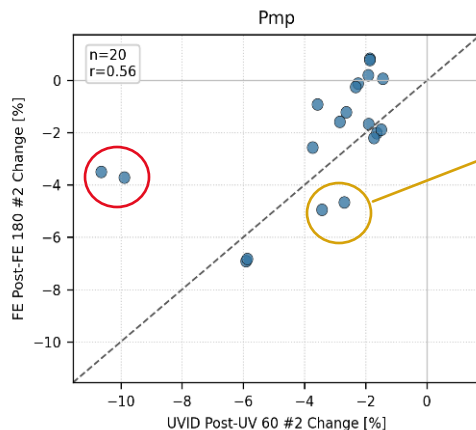
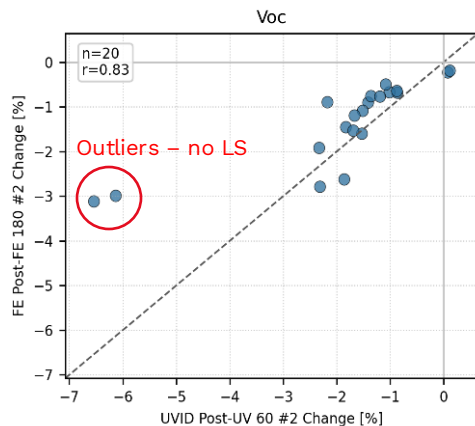


Most FE BOMs would not meet a <1% degradation warranty at the end of first year.

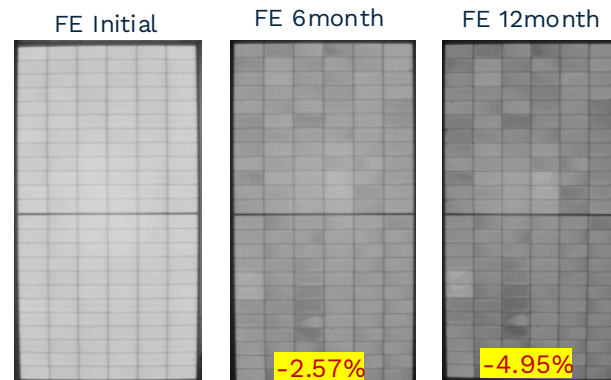
Correlation Between Outdoor Field and Indoor UVID Testing

- Common TOPCon BOMs between FE and UVID testing data.
- Voc exhibited a better correlation: **UVID120 test (55 kWh/m2 of UVF) corresponds to ~1.4 years of outdoor exposure in Davis, CA.**
- Pmp showed a weaker correlation: Impact of additional degradation modes (e.g. soiling, contact corrosion, etc.).

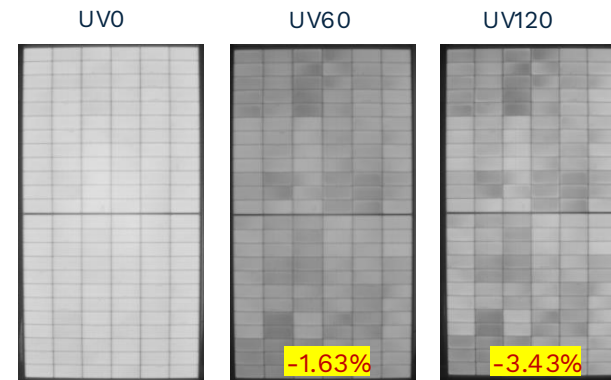
1 yr Outdoor



FE

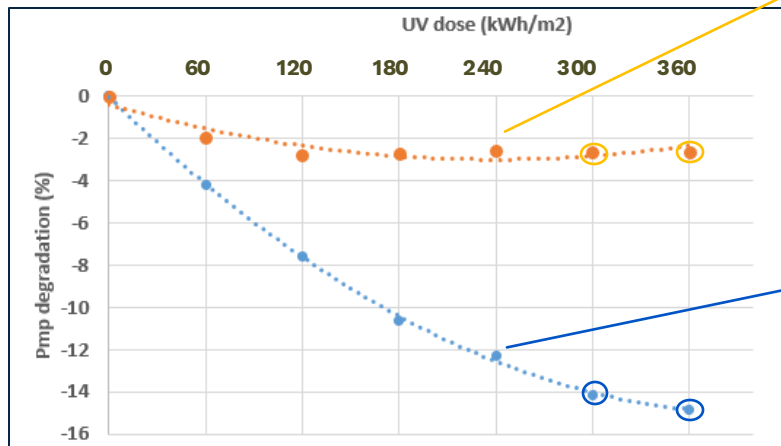


UVID

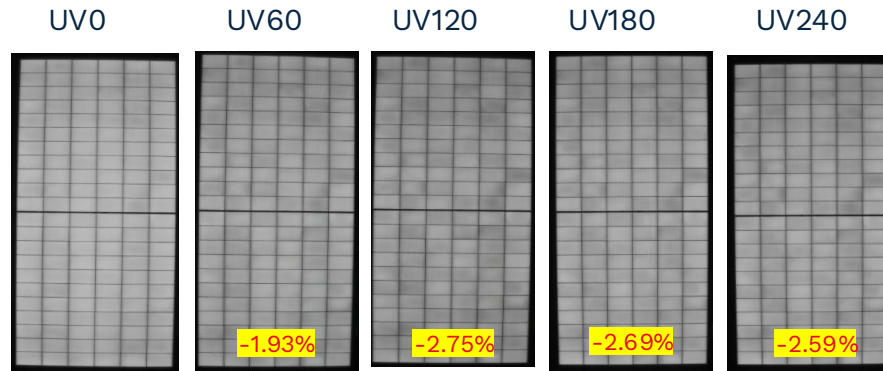


Long-term Reliability Testing

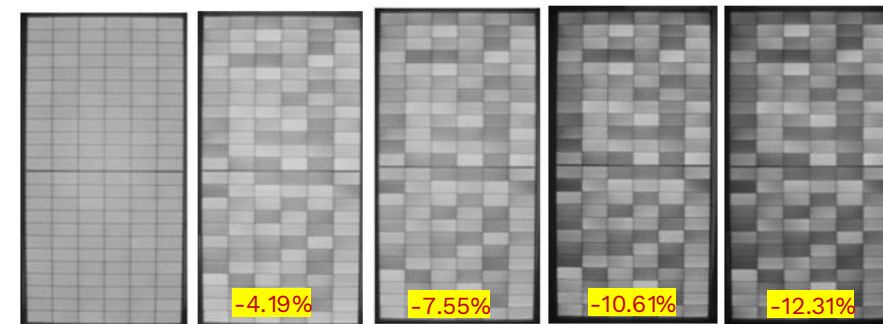
- UVID test run extended to 240 kWh/m².
- Project 1 (UV-stable modules) – Degradation saturated after UV120.
- Project 2 (UV-sensitive modules) – Degradation continues up to UV240



Project 1



Project 2





UVID Mitigation Strategies

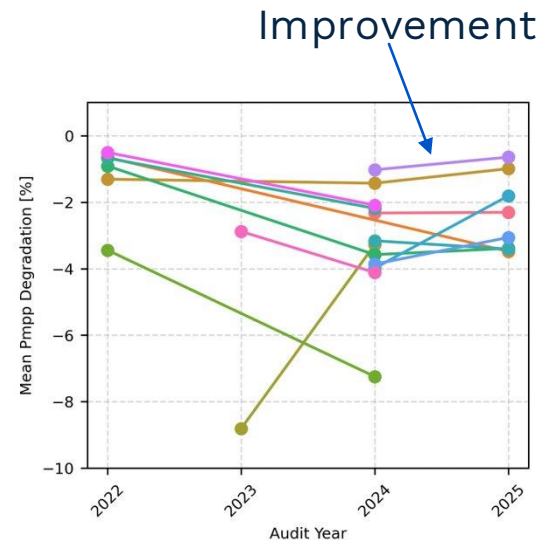
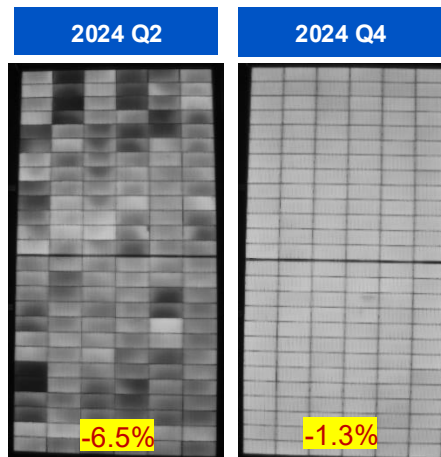
Kiwa PVEL

kiwa

creating trust, *driving progress*

UVID Mitigation at Cell Level

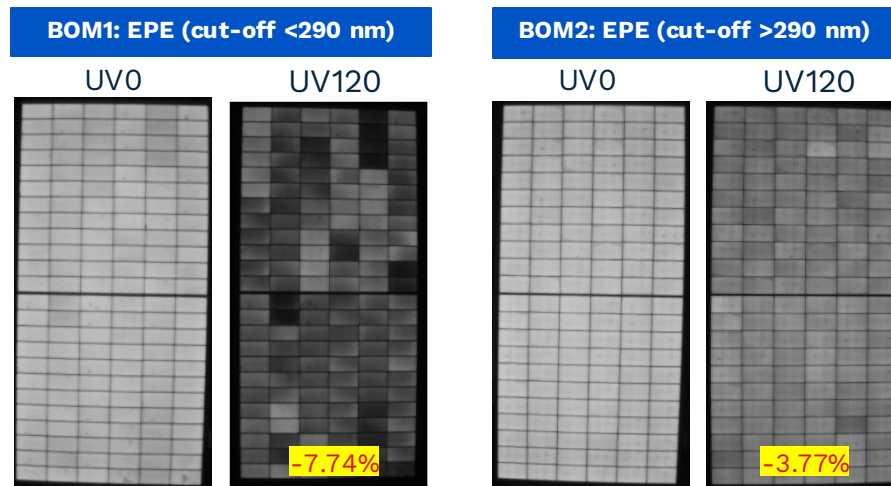
- Cell design improvements:
 - Front cell ARC/passivation layer process controls**
(thicker AlO_x, ARC and passivation stack uniformity)
 - Fixes associated with higher production costs.
- Example: A TOPCon BOM tested in 2024 Q2 with a retest in 2024 Q4.
 - Original: deg 6.5% (average), strong checkerboard pattern.
 - Retest: deg 1.3% (average), no EL anomalies.
- Many cell suppliers have improved their production quality processes.
 - Better performance in 2025 compared to 2024.**



Each line is an individual cell supplier.

UVID Mitigation at Module Level

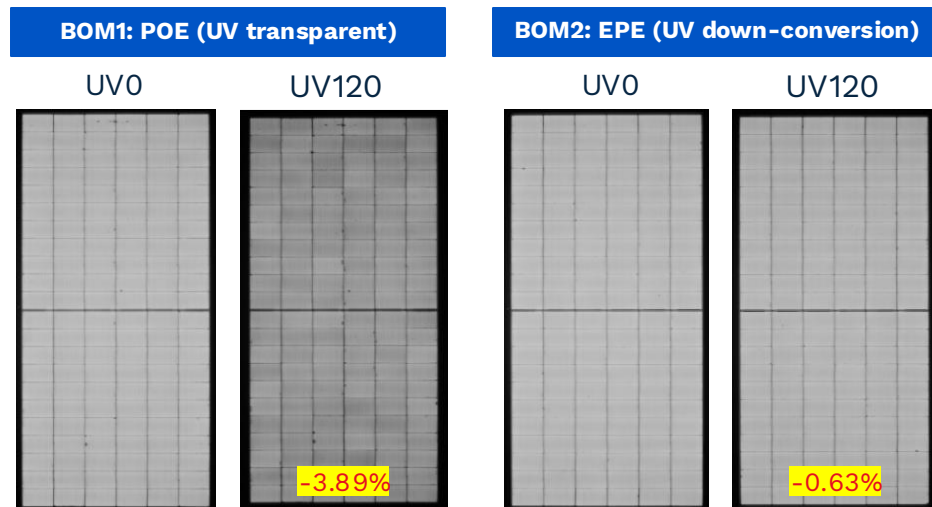
- UV blocking encapsulants can mitigate UVID.
- Cut-off wavelength of front encapsulant varies in the range of 220-380 nm.
 - **Higher degradation below 300 nm cut-off.**
- Example: TOPCon BOMs, same cell supplier and same encapsulant type but different UV cut-off.
 - BOM1 – EPE (cut off <290 nm) | EPE
 - BOM2 – EPE (cut off >290 nm) | EVA
- UVID extent can be lowered when tailoring the encapsulant cut-off band.



UVID Mitigation at Module Level

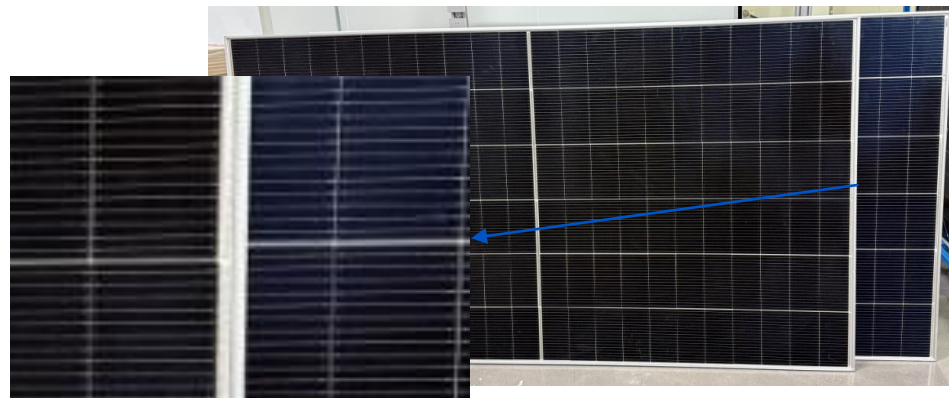
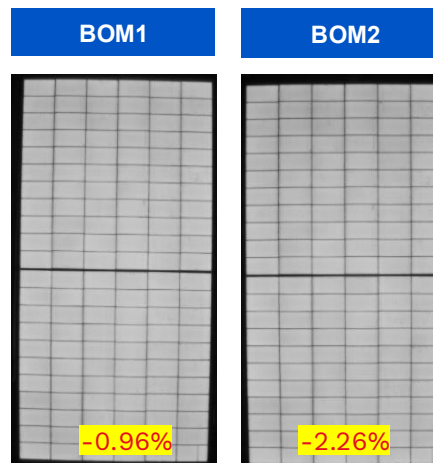
- **UV down-conversion encapsulants.**

- Converts UV light to visible photons, allowing higher efficiency and less prone to UVID.
- Example: same cell supplier but two different encapsulation schemes.
 - BOM1 – POE (UV transparent) | POE
 - BOM2 – EPE (UV down conversion) | EVA
- Currently used in HJT module designs, not much in TOPCon.
- Other reliability issues may arise, need to be tested further to validate stability.



Degradation Mechanism other than UVID

- **Not all UV degradation is cell-related.**
- Example: TOPCon BOMs, same encapsulant type and UV cut-off <290 nm
 - BOM1 – EPE (cut off 280 nm) | EVA
 - BOM2 – EPE (cut off 240 nm) | EVA
- BOM1 has no signs of degradation.
- BOM2 has negligible Voc loss and no checkerboard pattern in EL but significant Isc loss → **severe yellowing on the entire module.**
- Encapsulant additives/stabilizers play a role in degradation, that might be UV-unstable.



UVID Dosing



UV Dosing

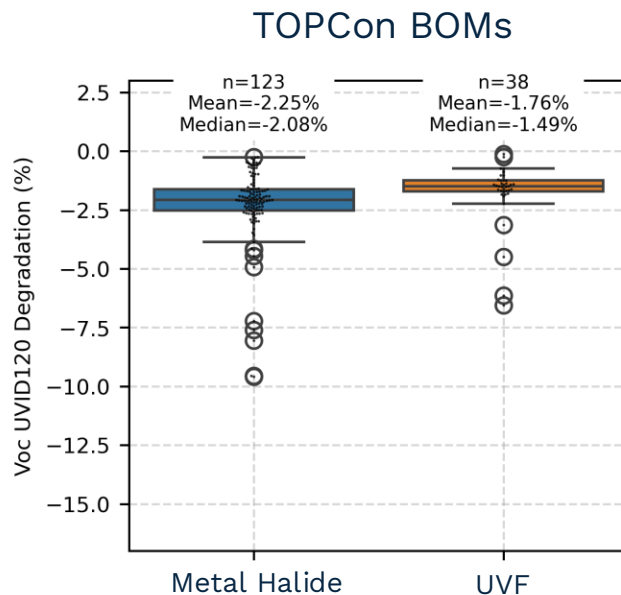
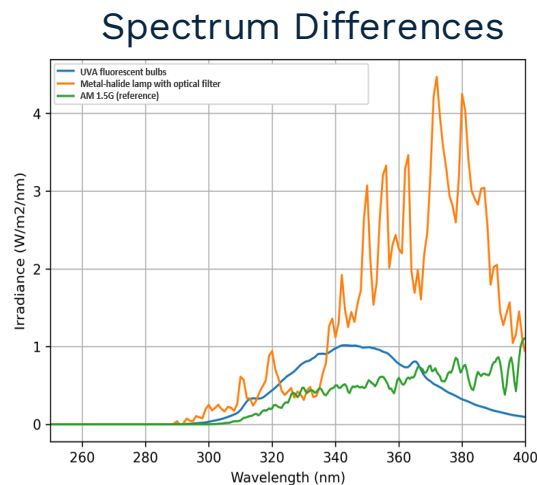
Kiwa PVEL

kiwa

creating trust, *driving progress*

UVF Dosing Change

- This work: UVID120 was achieved with 120 kWh/m² of ceramic metal halide (CMH) or **55 kWh/m²** of UV fluorescent 345 nm (UVF).
- Based on best evidence at the time, but we now suspect the UVF is under-dosed compared to CMH
- In PQP V12 (active now!) UVID120 achieved with **75 kWh/m²** of UVF



One BOM tested under both light sources

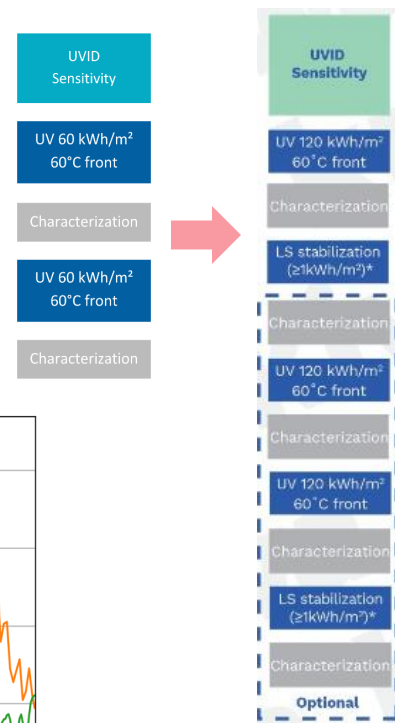
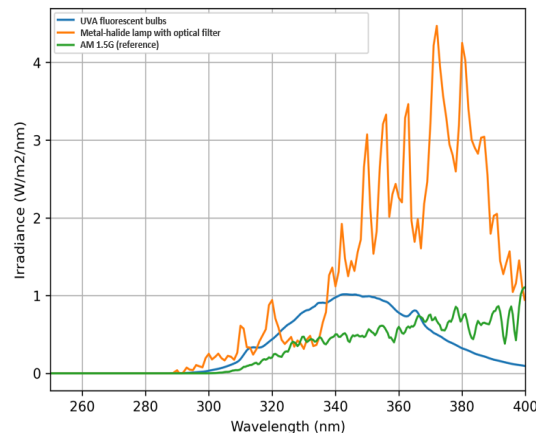
	Average values of 2 samples			
	PMP%	VOC%	ISC%	FF%
CMH	-2.65	-1.71	-0.55	-0.41
UVF	-1.89	-1.19	-0.44	-0.27

Voc Deg ratio: 1.4x
Pmp Deg ratio: 1.4x

1.4x on median

New Development in Kiwa PVEL's UVID Testing

- Streamlined UVID sequence in newer version of PQP
 - Eliminate interim UVID60 characterization in favor of a continuous 120 kWh/m² exposure
 - Option to **extend up to 360 kWh/m²** for BOMs that show higher UVID susceptibility to investigate the long-term reliability impacts.
- Increased effective dosage for UV fluorescent lamps.
 - 120 kWh/m² of metal halide = 75 kWh/m² of UVF
 - (Previously used 55 kWh/m² of UVF).

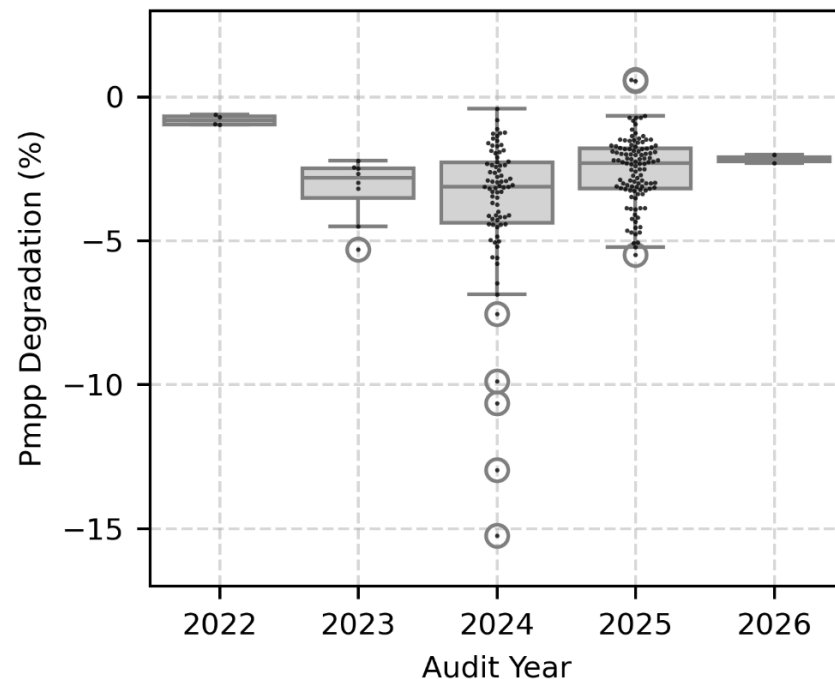


Key Takeaways

- UVID is a primary reliability issue for n-type modules. Some TOPCon and HJT BOMs are stable.
- UVID sensitivity depends not only on the cell architecture but also on the BOM.
- A short light soak under full spectrum can stabilize modules from metastability behavior in the dark post-UV exposure.
- Front cell ARC/passivation layer process controls and better encapsulant additives selection can help in mitigating UVID.
- Recent UVID testing on TOPCon modules showed a significant improvement in UV susceptibility.

UVID Stability is Improving, But is Not Solved Yet.

Kiwa PVEL's UVID test results (TOPCon only)



Note: Some big outliers are partially a result of dark metastability.

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.

*creating trust, **driving progress***

Contact us:
Kiwa PVEL
pvel@kiwa.com
www.kiwa.com/pvel

