2025 PV Module Reliability Scorecard

These are a few of my favorite things

Tristan Erion-Lorico, VP of Sales and Marketing
Kiwa PVEL

kiwa

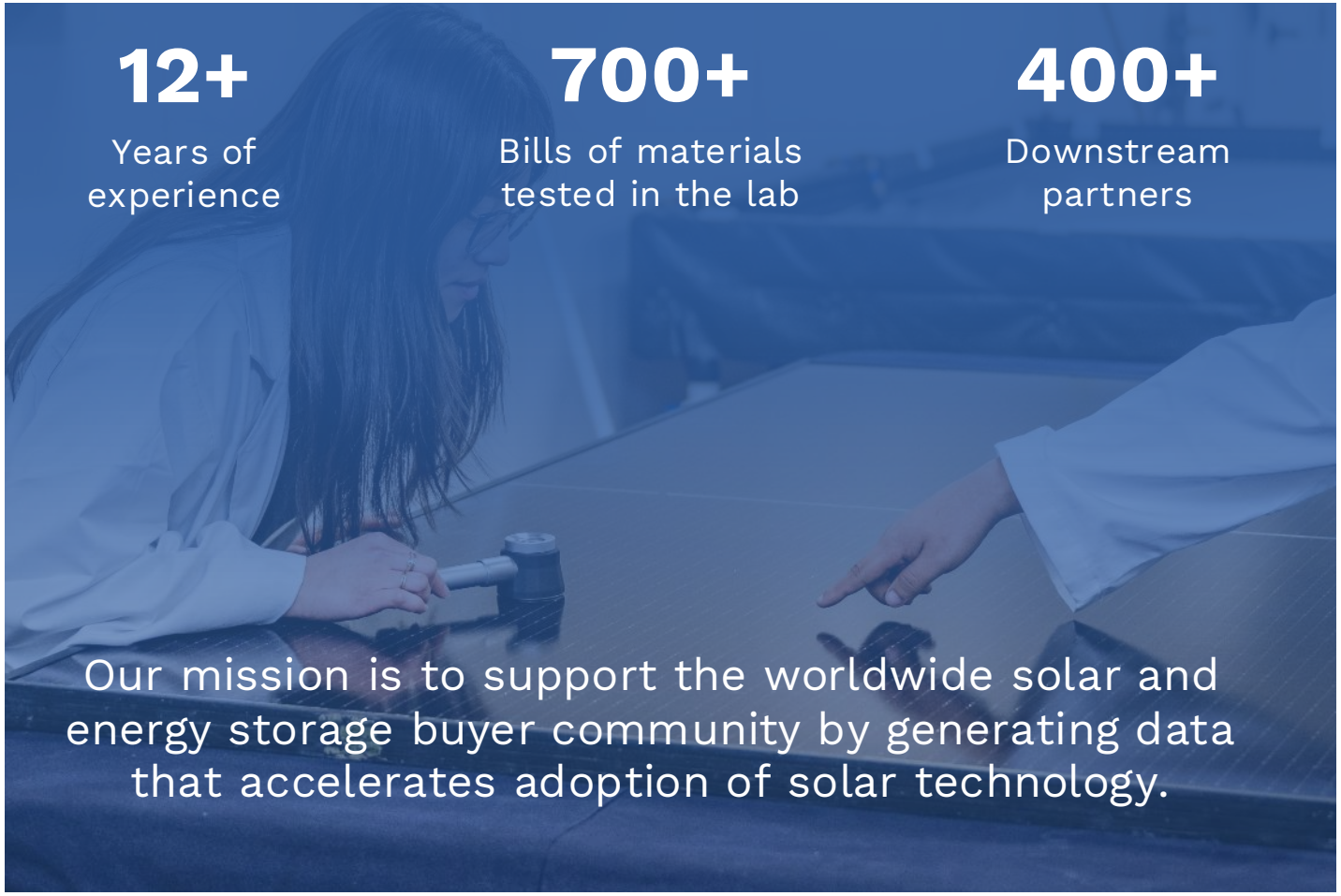
*creating trust, **driving progress***

Agenda

- Company Overview
- PQP Overview
- PV Module Reliability Scorecard Overview
- Selection of 2025 Scorecard Findings:
  - Main Key Takeaways
  - PAN and IAM Trends
  - Broken Modules
  - Delamination
  - Hail Results
  - UVID Spotlight
  - PQP Failures
  - Top Performers By Manufacturer
- Premium Partner Program

kiwa

Kiwa PVEL is the Independent Lab of the Downstream Solar Market



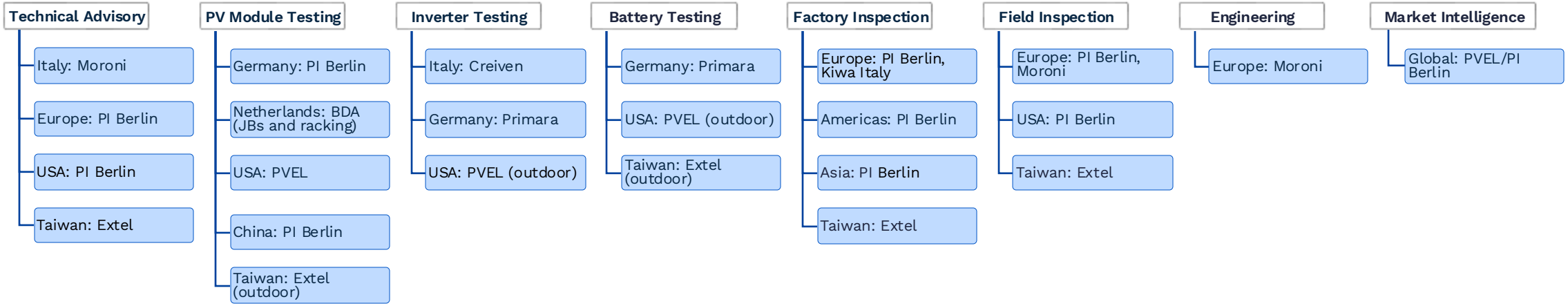
Services at a glance:

- 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

Kiwa Overview

- Kiwa is a global testing, inspection and certification (TIC) company, founded in 1948.
- Headquartered in Rijswijk, the Netherlands with more than 10,000 employees, working in over 37 countries. Kiwa is primarily active in renewable energy, construction, manufacturing, fire safety, medical devices, food & water.
- Kiwa's mission is to create trust by contributing to the transparency of the quality, safety and sustainability of products, services and organizations as well as of personal and environmental performance.
- Kiwa's solar businesses at a glance:



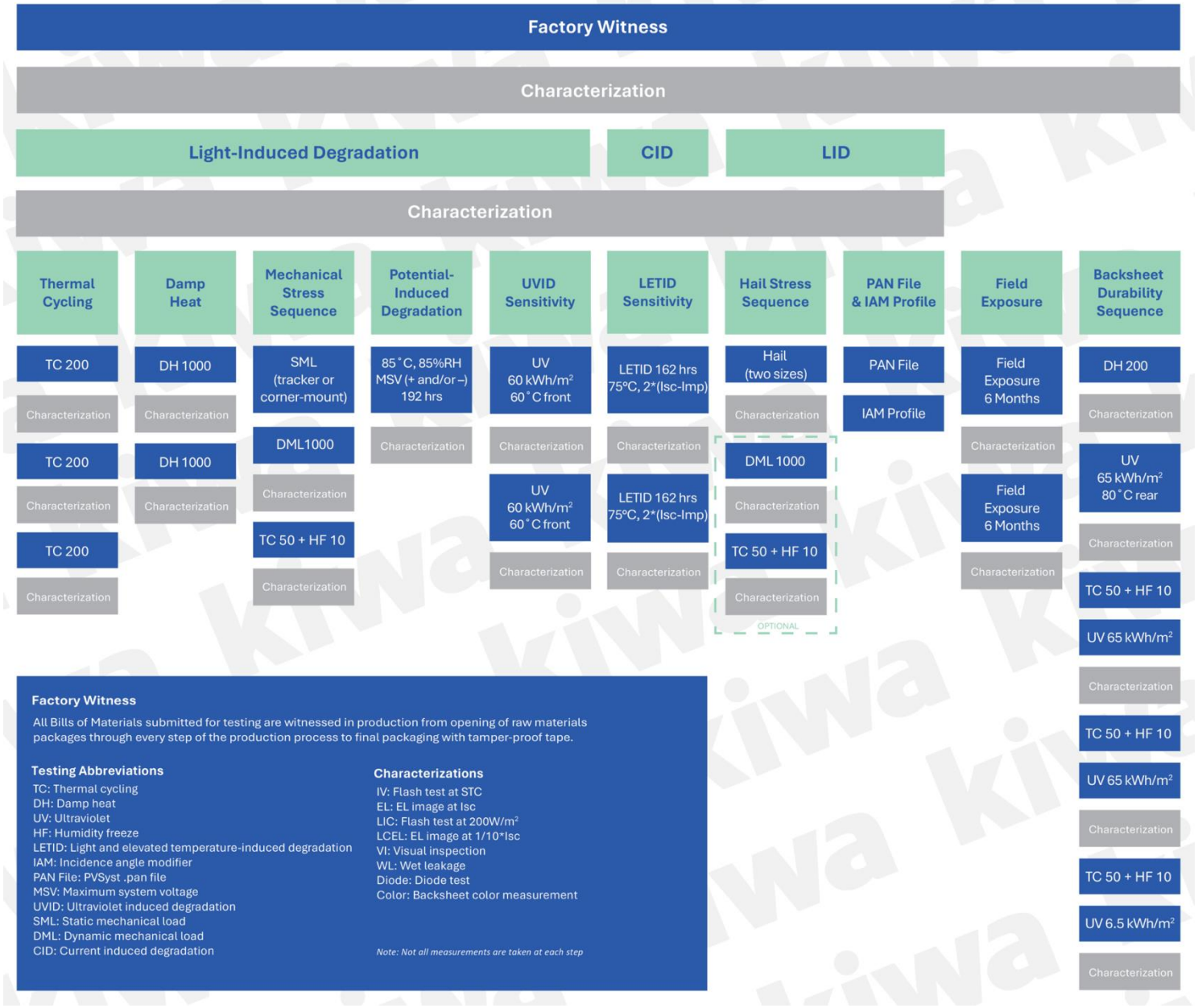
See more details at kiwa.com/solar

PQP Test Sequence

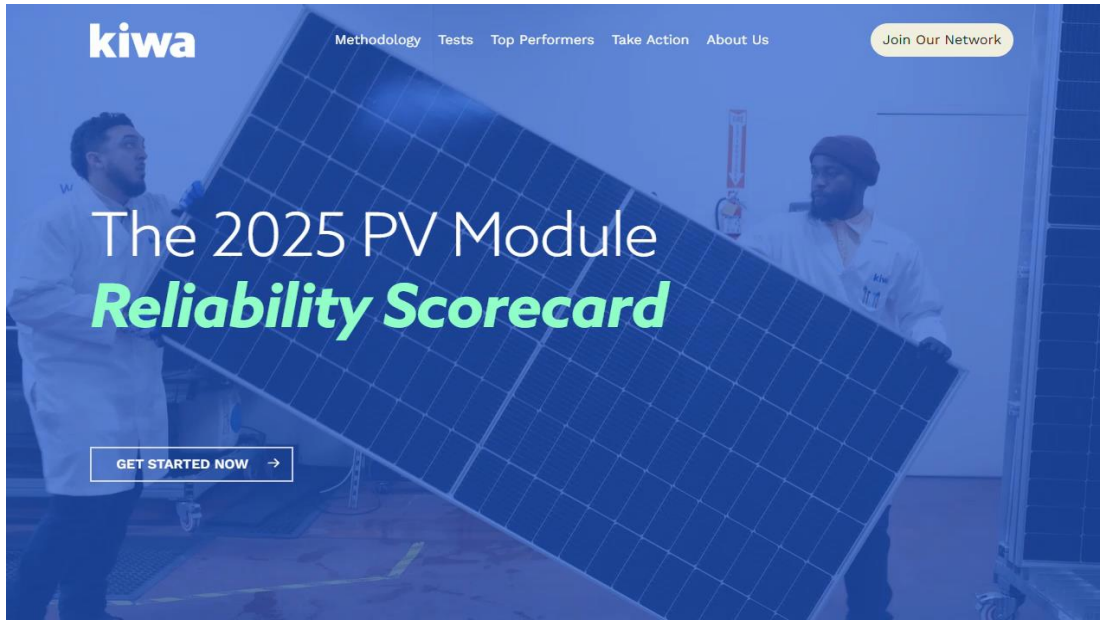
The PQP evolves every two years based on feedback from Kiwa PVEL's downstream partners, module manufacturers, and the industry's collective understanding of module failure modes and test mechanisms.

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.



PV Module Reliability Scorecard Overview



The annual PV Module Reliability Scorecards lists top performing modules and insights from Kiwa PVEL's PQP.

The 2024 Scorecard was accessed by more than **110,000 unique visitors** from over 170 countries.

TOP PERFORMER 2025 kiwa PV MODULE RELIABILITY SCORECARD

- To be eligible for the Scorecard, manufacturers must have:
  - Completed the PQP sample production factory witness within 18 months of the Scorecard publication and have new Top Performer results.
  - Submitted at least two factory-witnessed PV module samples to all PQP reliability tests, as per Kiwa PVEL's BOM test requirements.
- Top Performer criteria:
  - TC, DH, MSS, PID must have < 2% power degradation.
  - LID+LETID must have < 1% combined power degradation.
  - HSS must not experience glass breakage with ≥ 40 mm hail.
  - PAN must place in the top quartile for energy yield.
  - Top Performers must not have experienced a wet leakage failure, 'major' defect during visual inspection, or a diode failure for that particular test.

Key Takeaways from the 2025 PV Module Reliability Scorecard

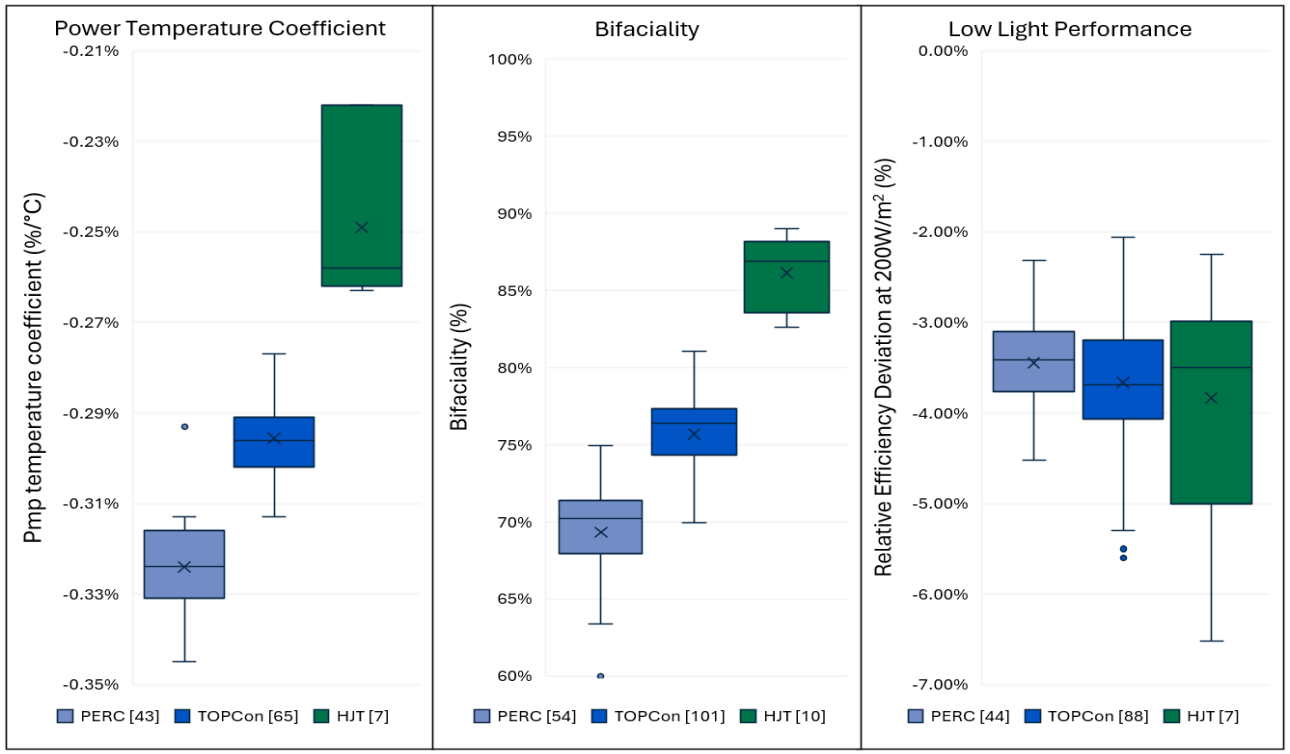
50 manufacturers are included in the 2025 Scorecard as Top Performers. Nine of them have at least one model type listed as a Top Performer in each of the seven tests.

Only 21 models achieved Top Performer status in all reliability tests (TC, DH, MSS, HSS, PID and LID+LETID). Of those, only three were Top Performers in those tests plus PAN performance.

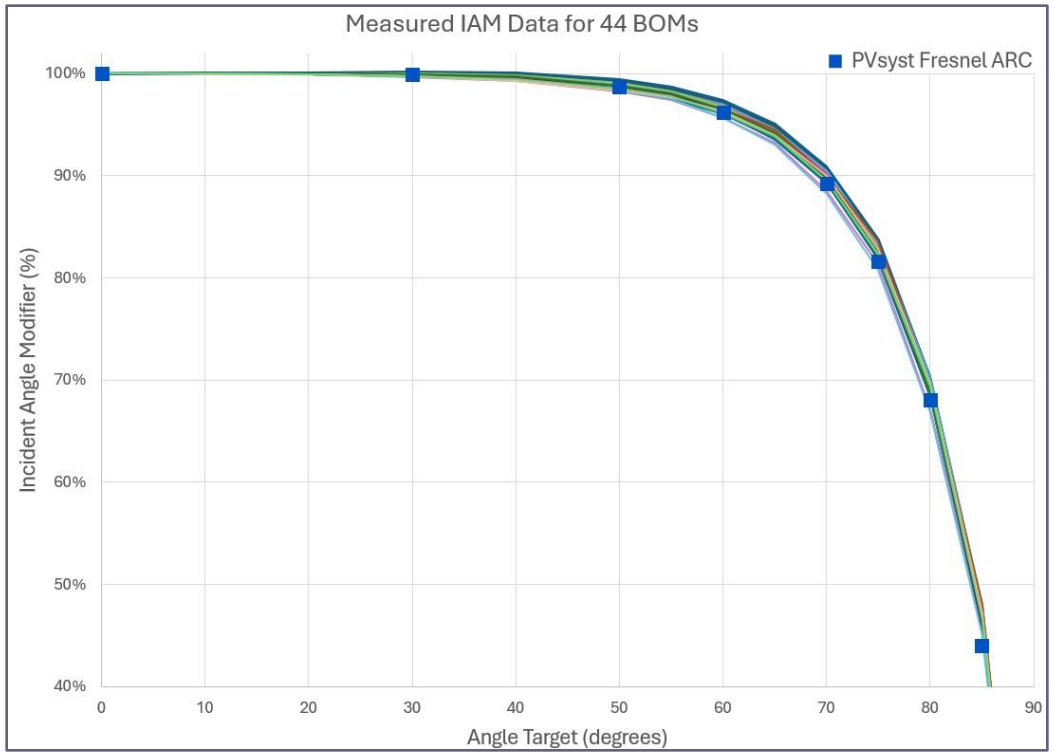
PID and PAN results improved and MSS, HSS and LID+LETID power loss continues to be minimal. But TC and DH have worsened, and the module breakage rate for MSS and HSS has increased. UVID remains a source of concern for some BOMs, but has improved for others.

83% of module manufacturers and 59% of BOMs had at least one test failure, up from the 66% and 41% reported in the 2024 Scorecard, respectively.

PAN and IAM Trends



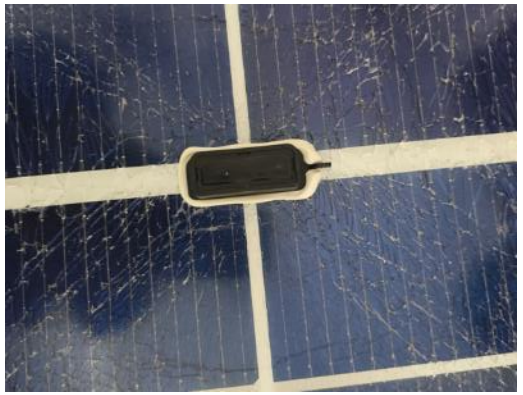
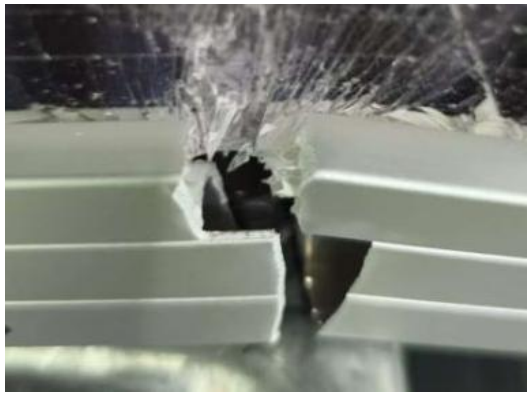
Key PAN file parameters of power temperature coefficient, bifaciality and low light performance results from PQP BOMs produced from 2022 to 2024.

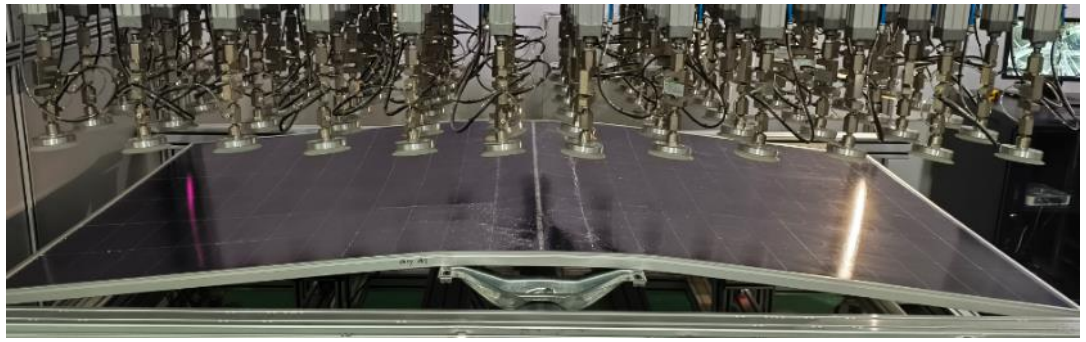


Kiwa PVEL's IAM test results for 44 BOMs from 2024 and Q1'2025 show strong consistency. PVsyst's Fresnel ARC default included for reference.

HJT > TOPCon > PERC for Pmp Temperature Coefficients and Bifaciality.
Mixed for Low Light Performance. TOPCon and PERC > HJT for IAM

Broken Modules – No Shortage of Examples




20% of BOMs undergoing the PQP's Mechanical Stress Sequence experienced broken glass or frames. Up from just ~7% in the 2023 and 2024 Scorecards.

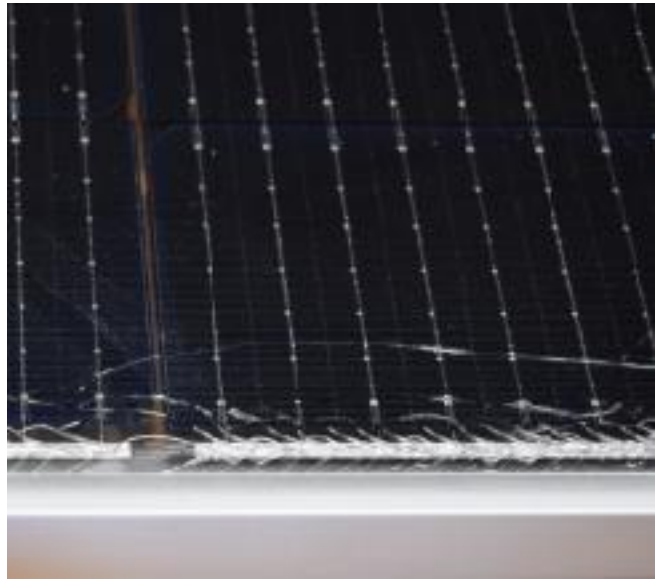
40% of manufacturers experienced at least one failure during MSS testing.

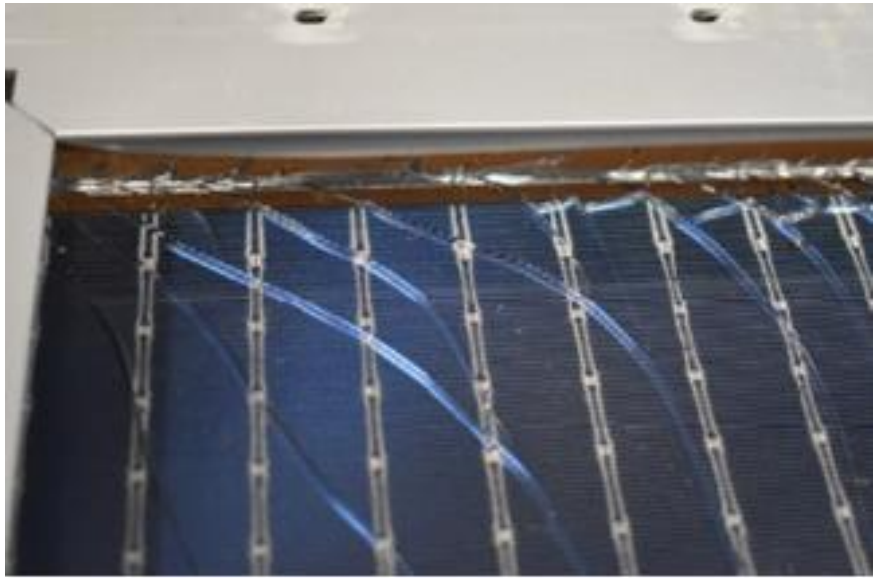
Broken Modules – Spontaneous Breakage Example

Kiwa PVEL is aware of glass//glass modules experiencing spontaneous glass breakage occurring in multiple countries, with multiple module model types, mounted to multiple tracker/racking solutions.

Six of 20 modules from one BOM exhibited a unique glass breakage pattern following outdoor LID.

The cracks along the busbars indicate a lack of encapsulant along the laminate edges, leading to edge-pinch induced stress concentration points between the metal busbar and the glass surface.

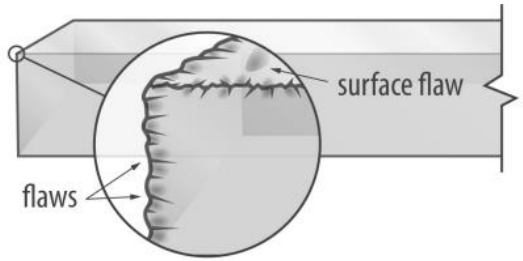


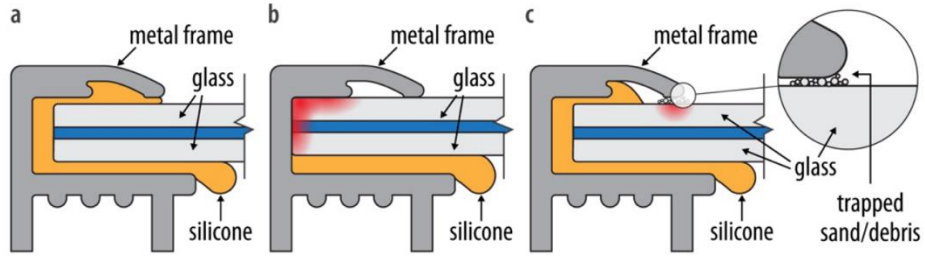


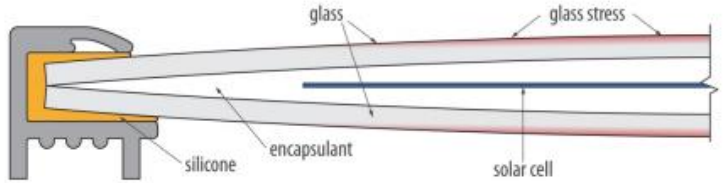
Glass cracking stemming from the module busbars in glass//glass modules can be prevented with thicker encapsulant and/or changes to lamination recipe.

Broken Modules – Possible Causes

- Kiwa's analysis of broken modules from the lab and field supports NREL's recent work[1] on this topic.
- A range of possible causes have been identified:
  - reduced glass strengthening
  - flaws within the glass edge and junction box mounting holes
  - weaker frame designs
  - more aggressive module mounting
  - contact between the glass and frame
  - laminate edge pinch
  - larger module areas

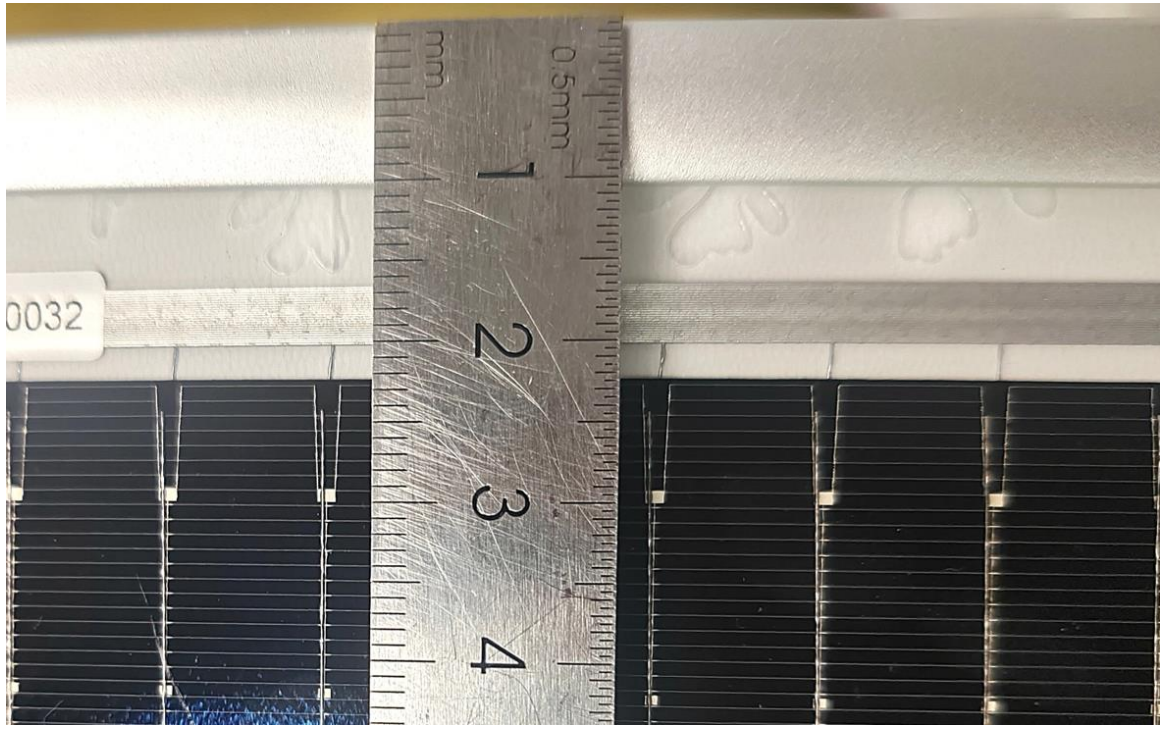




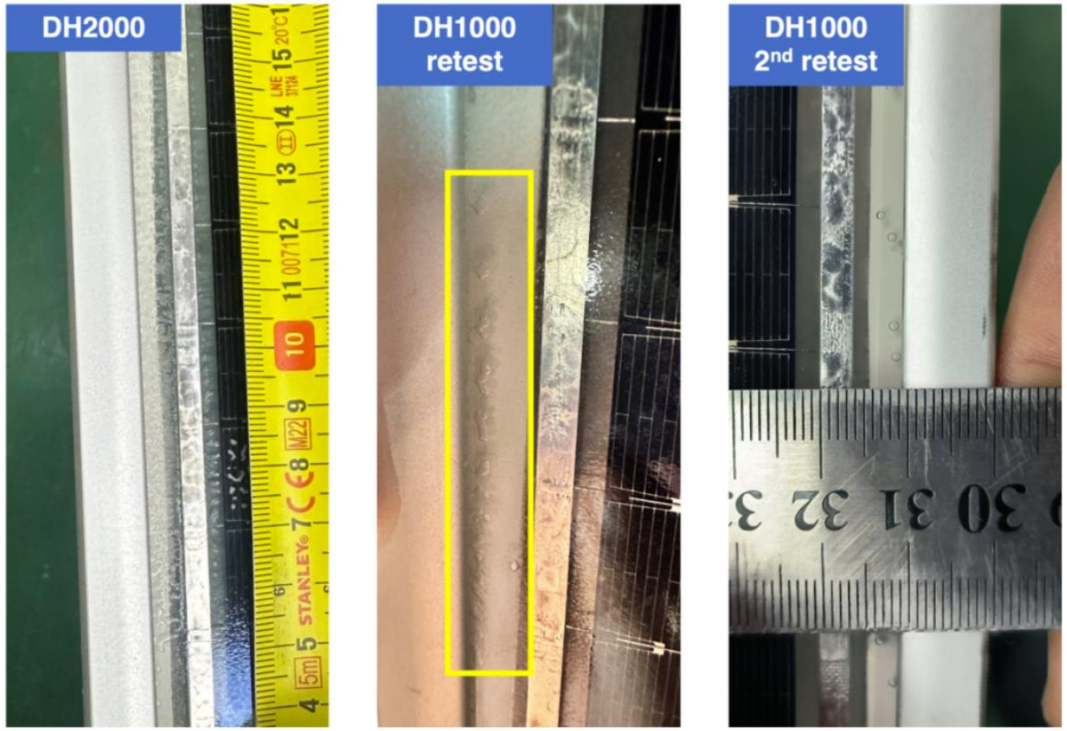


[1] https://www.nrel.gov/docs/fy25osti/91695.pdf

Delamination Defects Increase



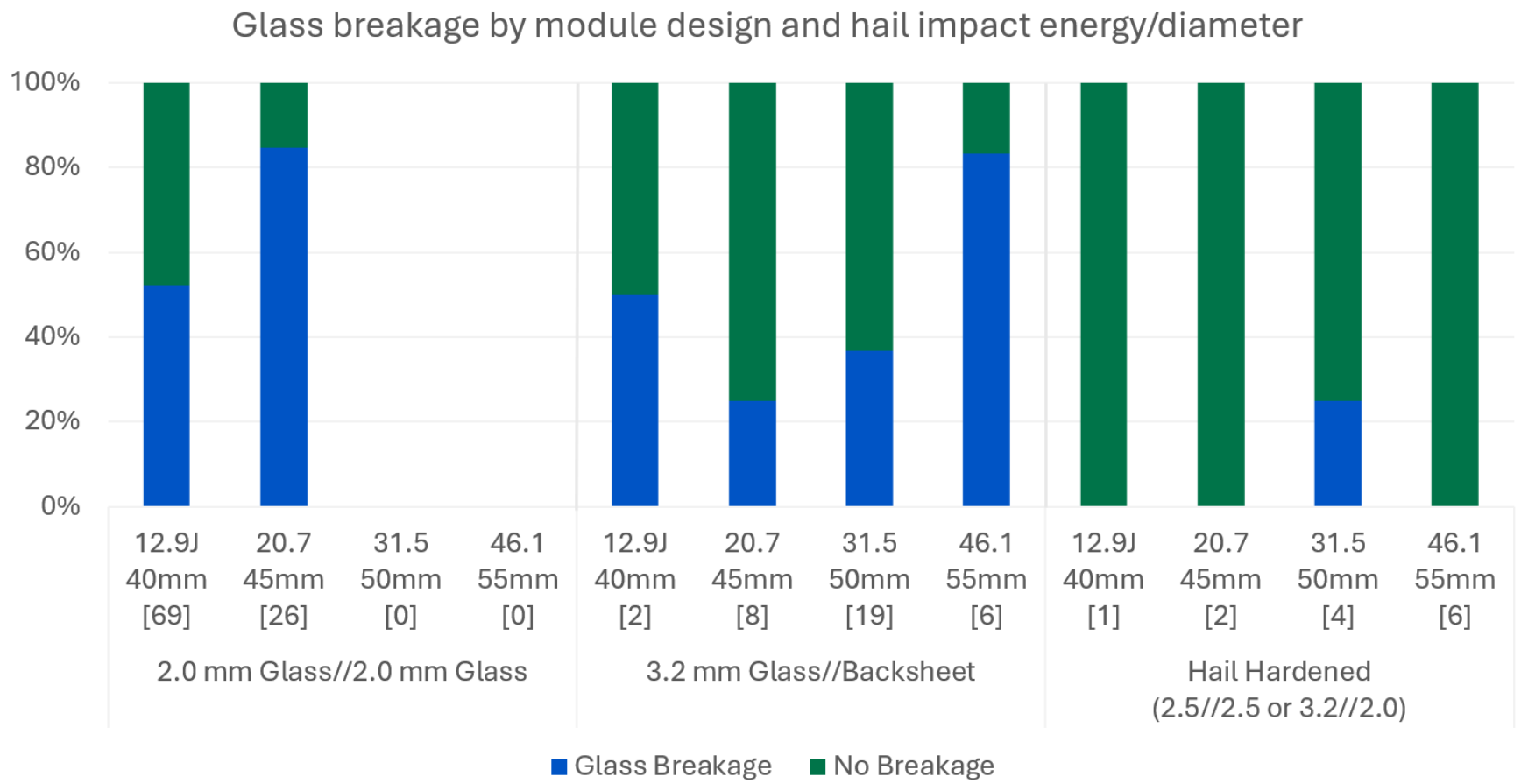
2025 Scorecard: Bubbles can be seen between the frame and the ribbon after TC600.



May 2024, PV Tech - *Outside the boxplot: Exploring Kiwa PVEL's PQP outliers*.

Affected 15% of manufacturers. Found at pre-stress, TC200 & 600, DH1000 & 2000, TC50+HF10, PID192. Solved via thicker and/or different encapsulant, extra encapsulant around parameter, *frames* around laminates during lamination, etc.

Hail Hardened Modules Show Promising Results

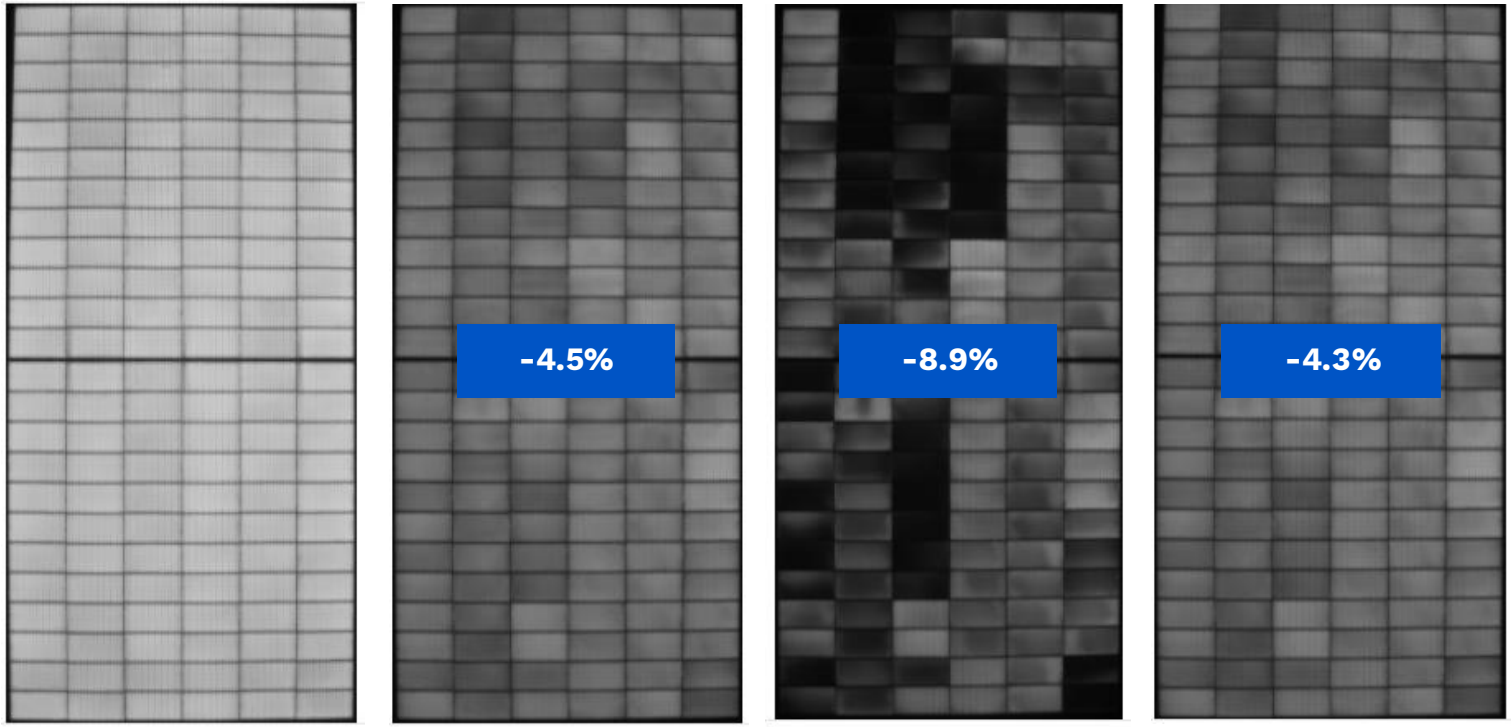


Glass breakage rates by kinetic energy and hail diameter by module type across the 2025 Scorecard dataset.

There is increased hail durability of 3.2 mm glass//backsheet modules compared to 2.0 mm glass//2.0 mm glass. The hail durability advantages of hail-hardened modules are also clearly shown.

UVID Test Result Spotlight

- Signs of metastability observed in some UVID-stressed and field-exposed modules.
  - Significant power loss occurred when the modules were stored in the dark after the test's conclusion.
- Stabilization procedure: **a short full-spectrum light soak for 0.1 kWh/m²** under open-circuit conditions for TOPCon modules, and 0.5 kWh/m² for HJT modules.
- Observed **partial recovery** of the total power loss related to dark storage degradation.
- Final degradation remained at >4%, signifying a clear susceptibility to UVID.

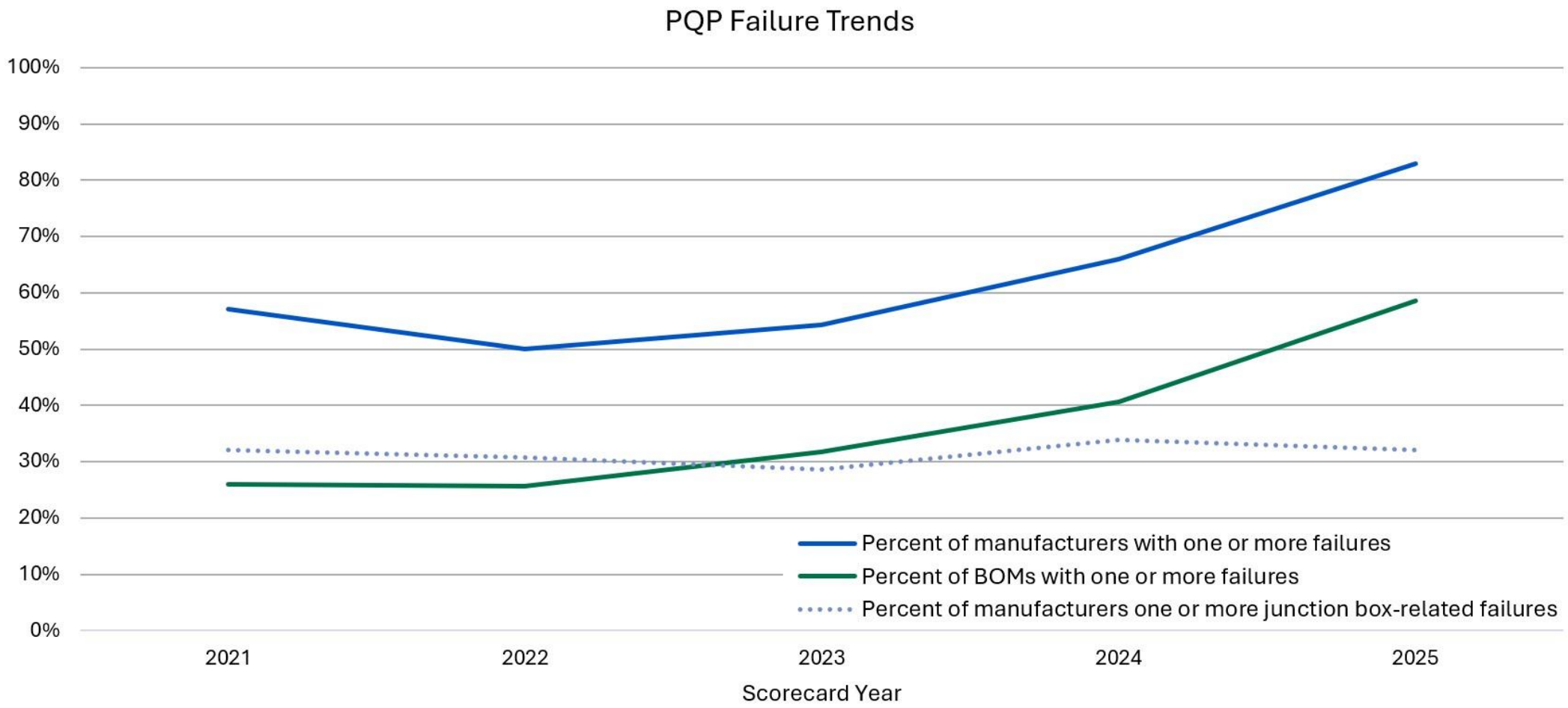


Initial Testing (Post LID) | *UVID120* | *Dark Storage (1 month)* | *Light Soak*

The EL images of UV-susceptible modules typically exhibit a 'checkerboard' pattern that is also seen in LETID-susceptible modules, indicating that cells are not uniformly affected by UVID stresses.

Front cell ARC/passivation layer process controls can help in mitigating UVID.
UV-blocking front encapsulants or UV down-conversion encapsulants can also lower UVID power loss.

PQP Failure Statistics



The percentage of manufacturers and BOMs experiencing at least one failure has been steadily rising.
The percentage of manufacturers experiencing one or more junction box-related failure remains consistently high.

2025 Scorecard Top Performers by Manufacturer

See more of the Scorecard including the Top Performer search tool at www.scorecard.pvel.com.

Kiwa PVEL's Premium Partner Program

- Module purchasing companies can subscribe to the Premium Partner Program to receive a quarterly Dashboard of Kiwa PVEL's Product Qualification Program (PQP) test results. This allows for easy Approved Vendor List (AVL) management and identification of potential new suppliers.
- PQP results from over 60 module manufacturers are included in the Dashboard, with over 40 manufacturers sharing their non-anonymized results. Over 250 BOMs are included, with almost 70% of BOMs non-anonymized.

Manufacturer	Module Model & Datasheet	PVEL Project #	BOM #	Factory Location	Wafer Edge Length (mm)	PQP Pass / Fail	Wet Leakage Result	Visual Inspection Result	TC 600	DH 2000/Post-BO	MSS	P.I.D. 192 (Negative Bias)	P.I.D. 192 (Positive Bias)	LID (>60 kWh/m2)	LETID (post-486h)
Manufacturer B	BBB-BB-BBB	2222	2	China	182	Pass	Pass	Pass	-2.15%	Test not required	Test not required	Test not required	Test not required	Test not required	-3.48%
Manufacturer B	BBB-BB-BBB	2222	3	China	182	Test not required	Pass	Pass	Test not required	Test not required	Test not required	Test not required	Test not required	Test not required	-3.57%
Manufacturer C	CCC-CC-CCC	3333	1	China	166	Pending	Pass	Pass	Pending	-0.09%	Test not required	-0.20%	Test not required	NOD	-3.53%
Manufacturer C	CCC-CC-CCC	3333	1	China	182	Pending	Pass	Pass	Pending	Pending	Test not required	Pending	Test not required	Pending	-3.35%
Manufacturer D	DDD-DD-DDD	4444	1	China	158.75	Pending	Pass	Pass	Pending	Pending	-2.97%	Pending	-1.04%	-0.27%	-0.50%
Manufacturer D	DDD-DD-DDD	4444	2	China	166	Pass	Pass	Pass	-1.11%	-0.28%	Test not required	-0.58%	Test not required	NOD	-0.57%
Manufacturer D	DDD-DD-DDD	4444	3	China	158.75	Pass	Pass	Pass	NOD	NOD	-0.50%	-0.08%	Test not required	-1.02%	-1.34%
Manufacturer D	DDD-DD-DDD	4444	1	China	182	Pending	Pass	Pass	Pending	-1.19%	Test not required	-1.95%	-1.29%	-0.24%	-1.23%
Manufacturer E	EEE-EE-EEE	5555	1	China	158.75	Pass	Pass	Pass	-2.16%	-0.28%	Test not required	-0.12%	Test not required	-0.85%	-1.01%
Manufacturer F	FFF-FF-FFF	6666	1	Turkey	158.75	Pass	Pass	Pass	-3.76%	-0.75%	-1.47%	-4.03%	Test not required	-0.11%	-1.65%
Manufacturer F	FFF-FF-FFF	6666	1	Turkey	182	Pending	Pass	Pass	Pending	Test not required	Test not required	Test not required	-0.99%	Test not required	-1.02%
Manufacturer F	FFF-FF-FFF	6666	2	Turkey	182	Pending	Pass	Pass	Test not required	-1.43%	Test not required	-2.27%	-0.85%	NOD	-1.13%
Manufacturer G	GGG-GG-GGG	7777	1	China	158.75	Pass	Pass	Pass	Test not required	Test not required	Test not required	-1.84%	Pending	-0.32%	-0.94%
Manufacturer G	GGG-GG-GGG	7777	2	China	158.75	Pass	Pass	Pass	Test not required	Test not required	Test not required	-1.17%	Test not required	Test not required	-1.60%
Manufacturer G	GGG-GG-GGG	7777	1	China	158.75	Fail	Pass	Fail PID-192	-1.72%	-2.07%	Test not required	-3.86%	Test not required	NOD	-2.09%

- A selection of the current Premium Partner Program subscribers:

Thanks for coming to Napa!

www.scorecard.pvel.com

creating trust, ***driving progress***

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