Top 3 Module Reliability Risks

2025’s three most common findings in PQP testing

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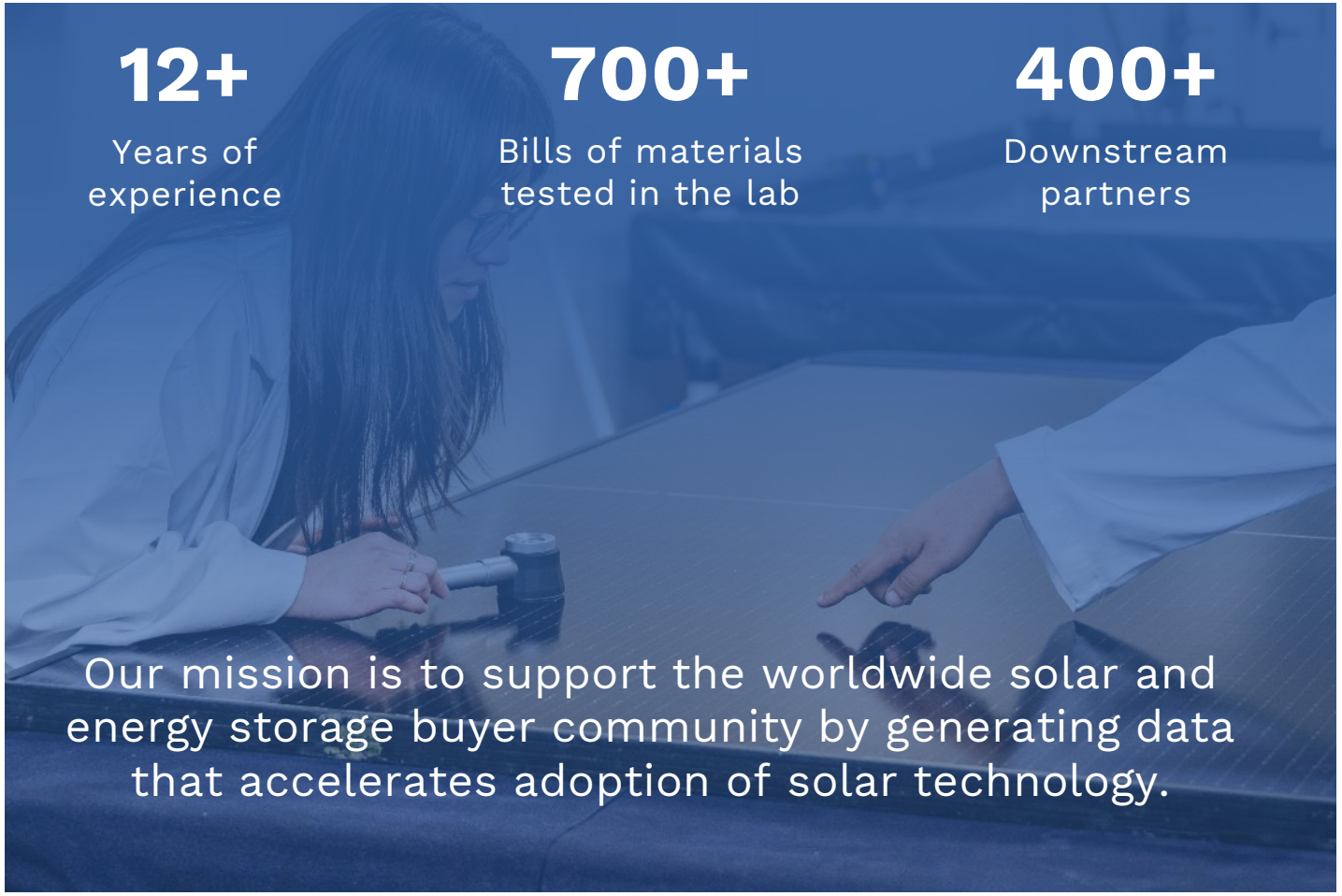
*creating trust, **driving progress***

Agenda

- Company Overview
- PQP Overview
- The Top Three Reliability Risks
  - #3 – UVID
  - #2 – Module Breakage
  - #1 – Delamination
- Premium Partner Program

Kiwa PVEL is the Independent Lab of the Downstream Solar Market



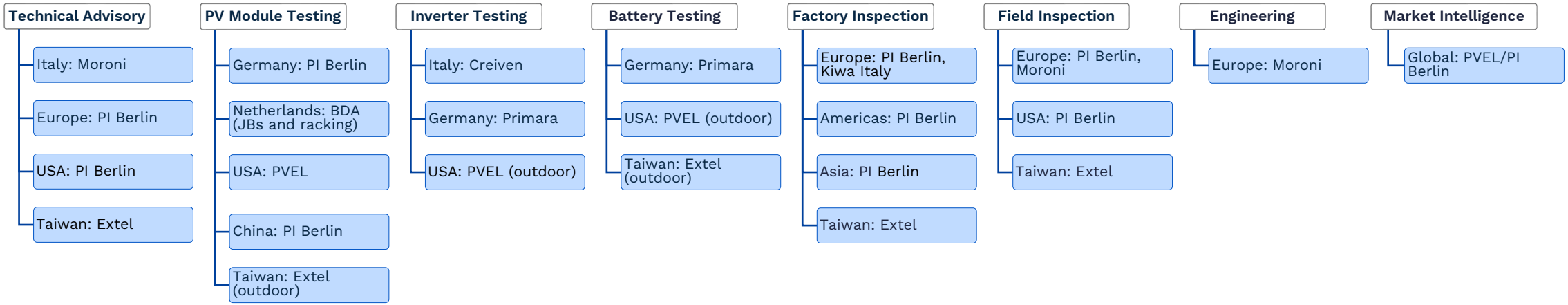
Services at a glance:

- 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:



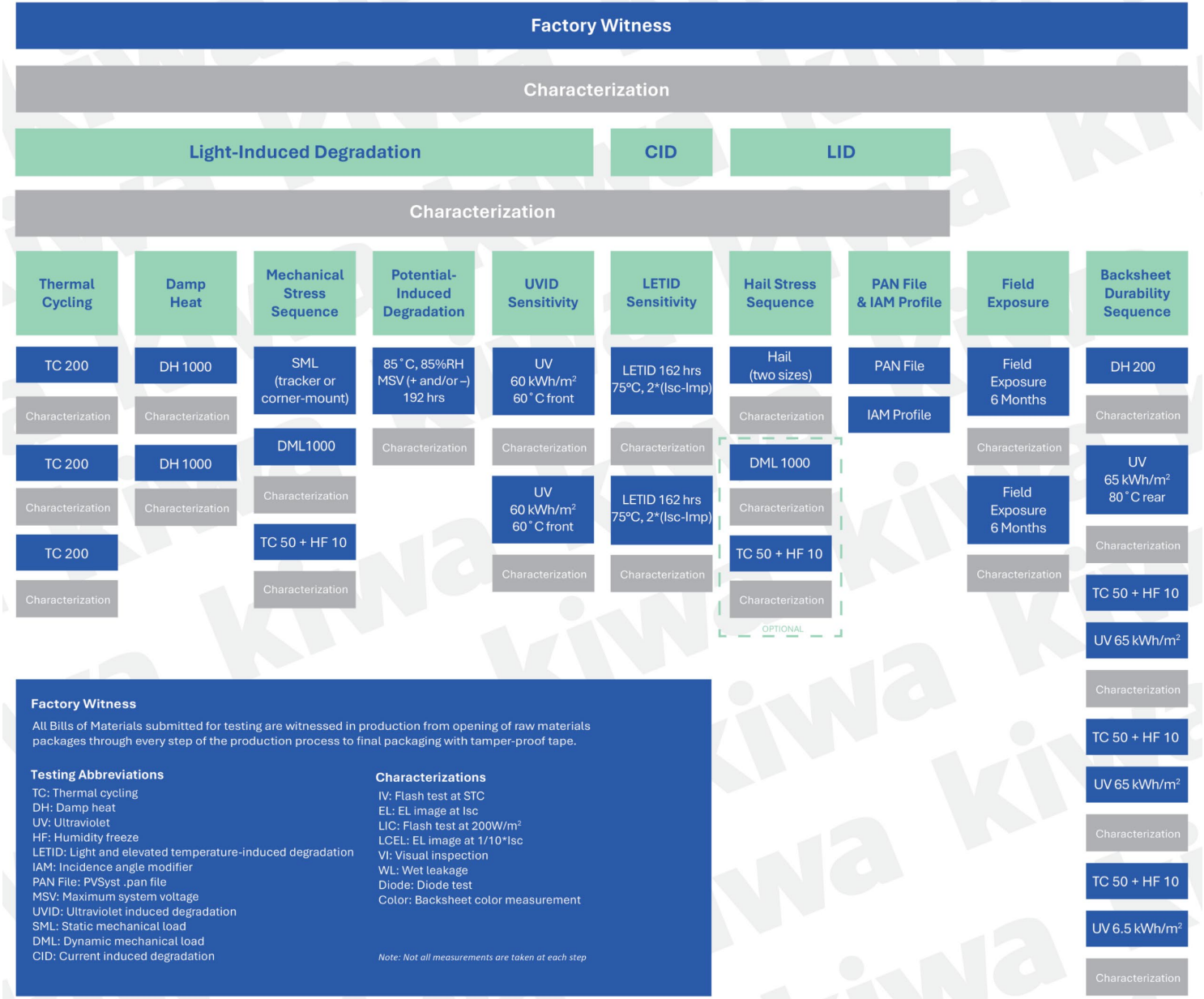
See more details at kiwa.com/solar

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.



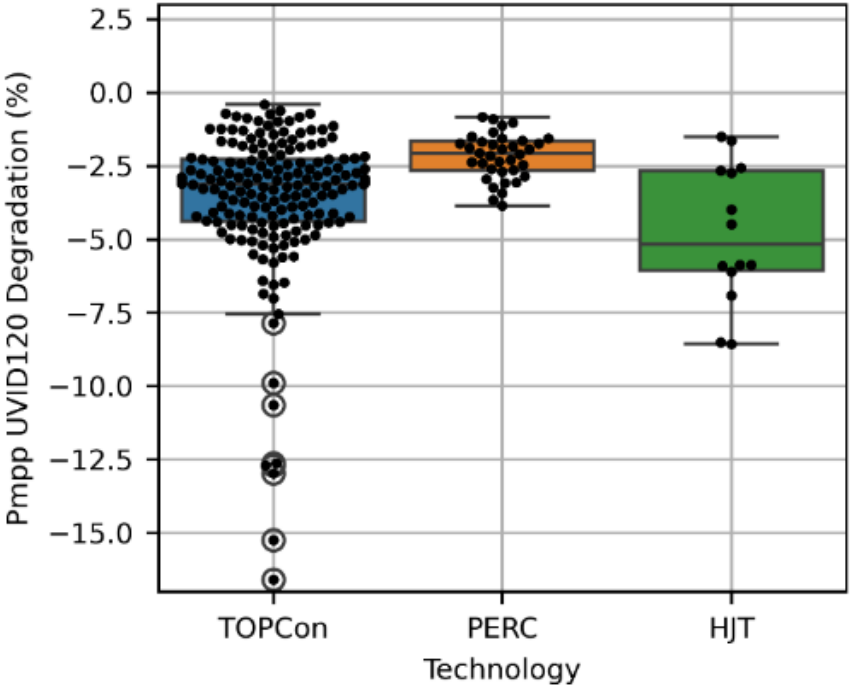
#3 – UVID – Results at a Glance

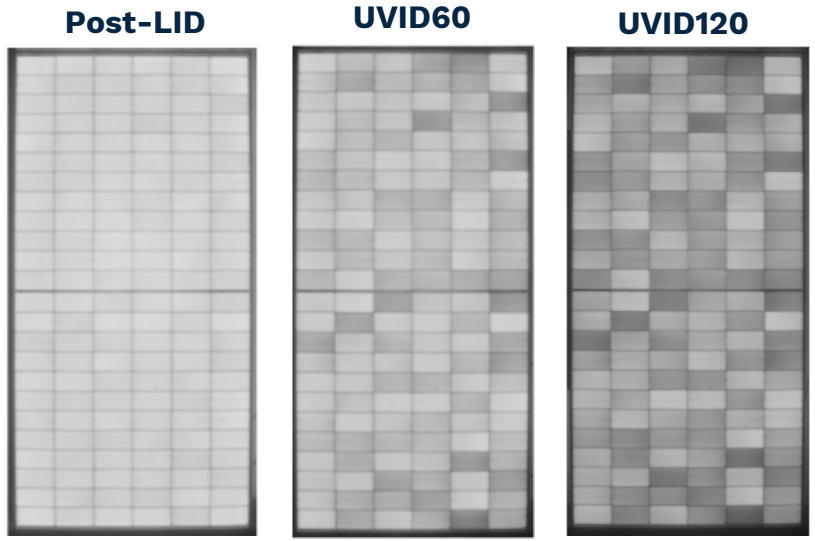
- Largest “public” UVID dataset (2024-2025):
  - Total **378 modules** (~189 BOMs) evaluated
  - 77% TOPCon modules, predominant technology

- Characteristic **“Checkerboard” pattern** in EL images
  - Cells degrade randomly within the module, with no distinct pattern with position.

- **UVID affects all TOPCon, PERC and HJT modules**
  - TOPCon and HJT modules showed a broad range of susceptibility (0.6% to 16.6%)
  - Indicating the variability in bill of materials, cell architecture, and processes.
  - UVID-stable TOPCon BOMs are available.

- UVID solutions:
  - Front cell ARC/passivation layer process controls
  - UV-blocking front encapsulants or UV down-conversion encapsulants



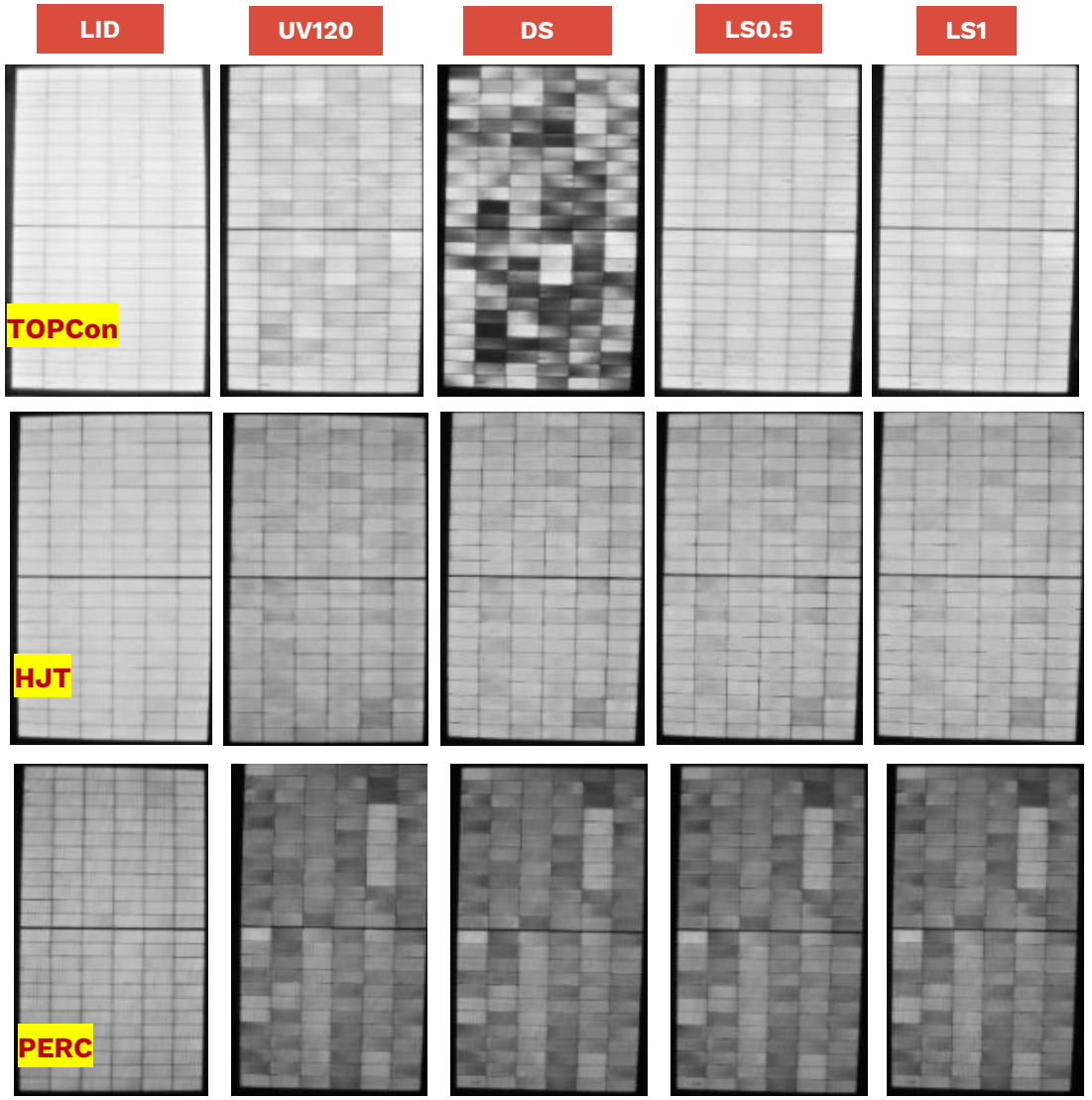


#3 – UVID – Dark Storage Metastability & Stabilization

- UVID-sensitive TOPCon modules suffer from dark storage (DS) degradation (metastability).
  - Greater the dark-storage, higher is the degradation.

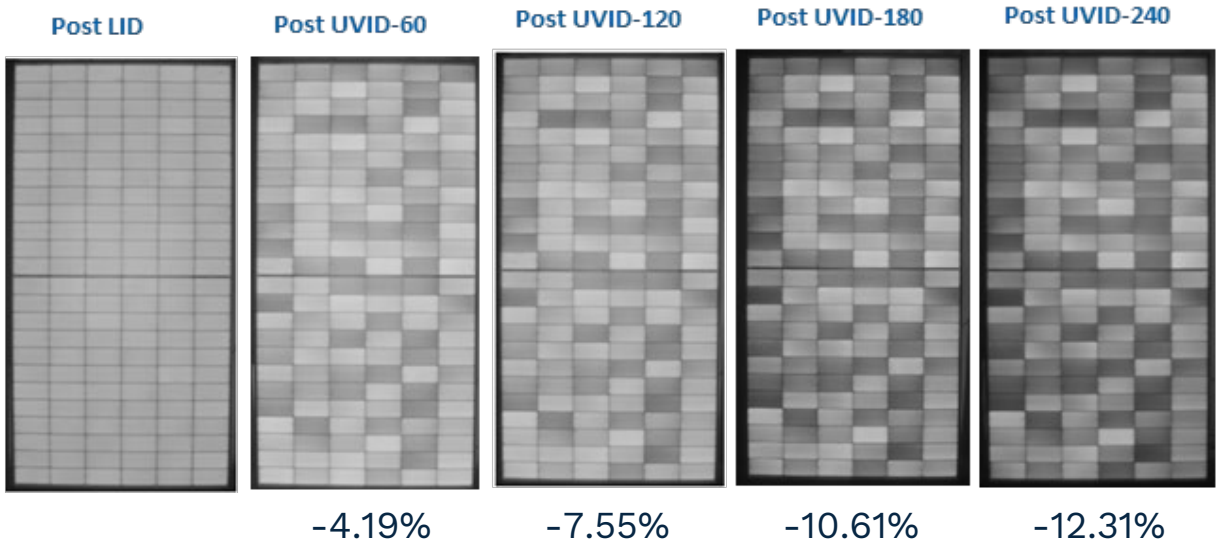
- **This degradation is recoverable under full spectrum light-soak (LS).**
  - TOPCon - Fast and effective recovery (Voc/Isc/FF).
  - HJT - Obvious recovery but at slower rate (FF).
  - PERC - No obvious degradation or recovery.

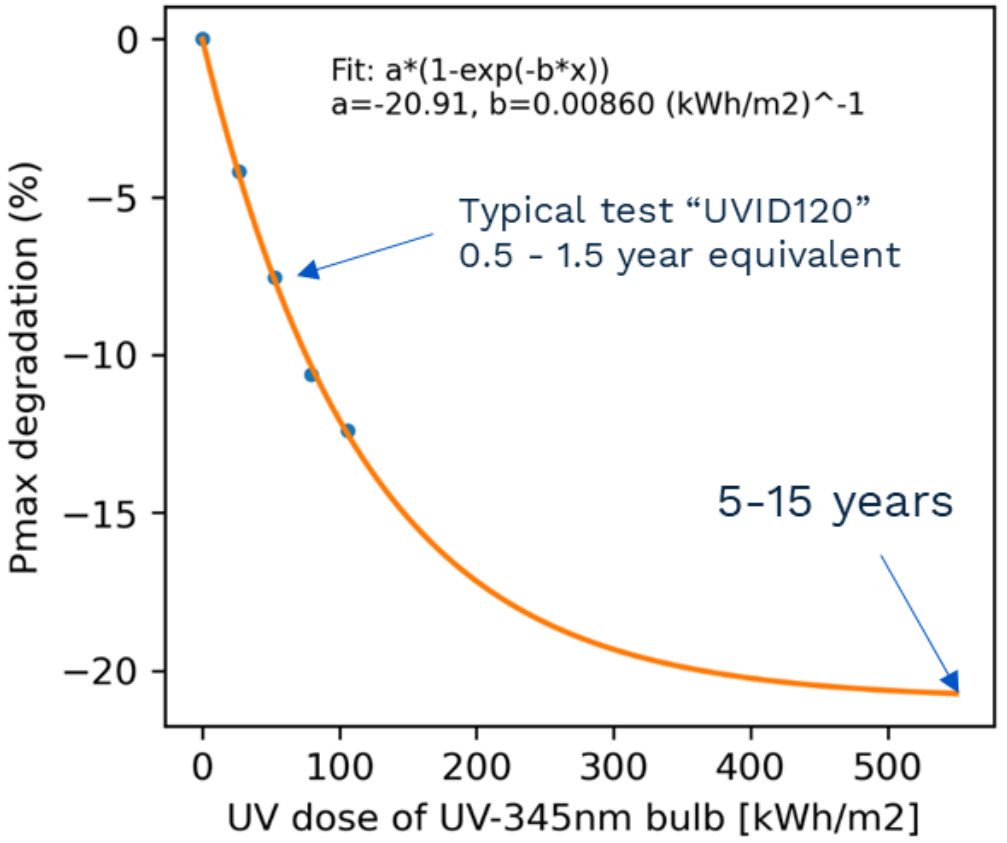
	LID	UVID120	Dark Storage (60 days)	LS 0.5kWh/m^2	LS 1kWh/m^2
Bad TOPCon	0.40%	-5.60%	-12.30%	-5.70%	-5.60%
Good TOPCon	-0.10%	-1.40%	-2.60%	-2.40%	-2.30%
HJT	0.10%	-4.50%	-6.30%	-6.00%	-5.50%
Bad PERC	0.00%	-3.00%	-3.80%	-3.80%	-3.70%
Good PERC	0.00%	-1.90%	-2.30%	-2.40%	-2.30%



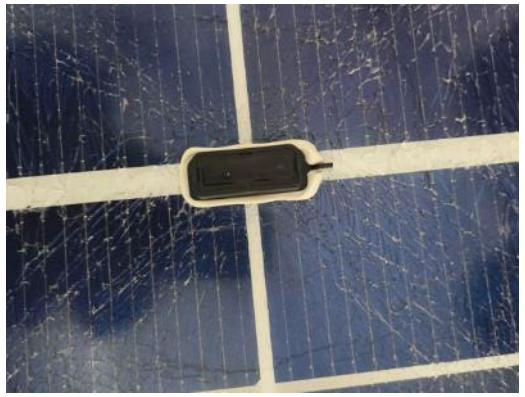
#3 – UVID – Extended UVID Testing

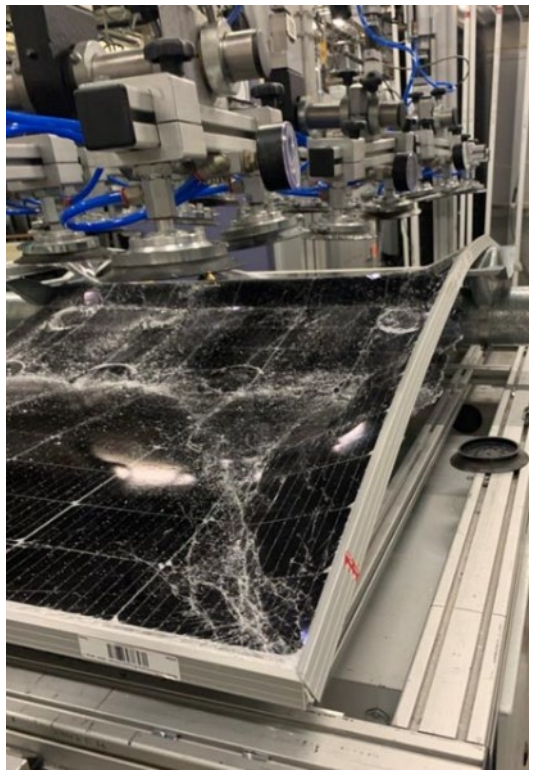
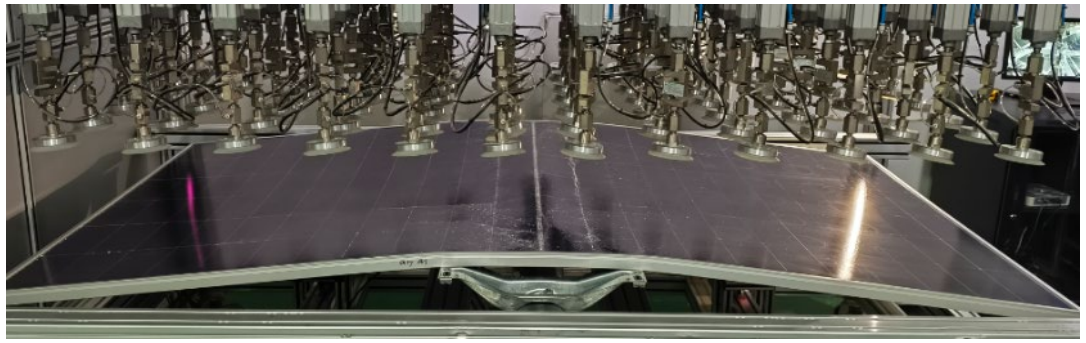
- Industrial TOPCon module with high UV sensitivity.
- Extrapolated using exponential fit:
  - Saturation occurs after approx. 15 years of field aging (550 kWh/m^2 of UV-345nm bulbs).
  - Module that loses -7.5% after “UVID120” expected to saturate at -21% power degradation.
- Kiwa PVEL will most likely introduce extended UVID testing in PQP v12 as optional.





#2 – Module Breakage – No Shortage of Examples

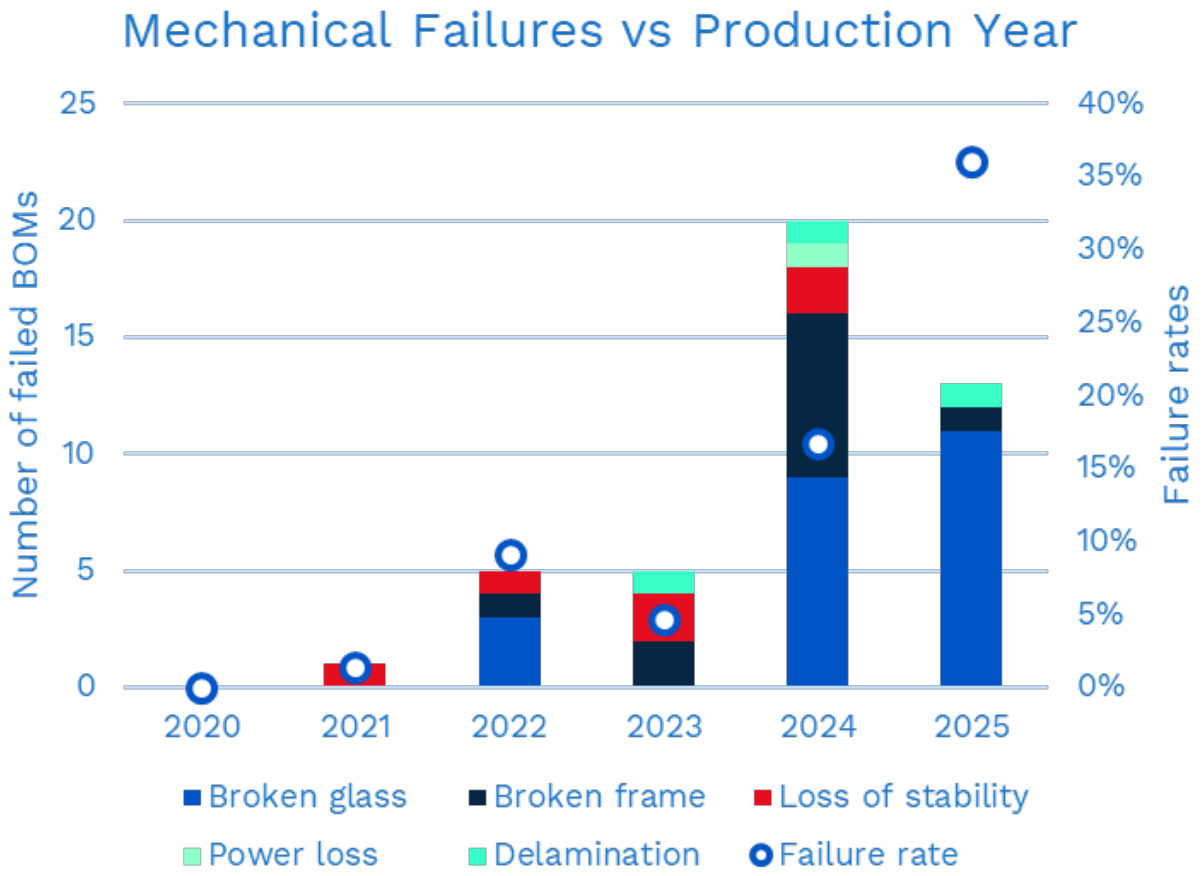




20% of BOMs undergoing the PQP's Mechanical Stress Sequence experienced broken glass or frames. Up from just ~7% in the 2023 and 2024 Scorecards.

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

#2 – Module Breakage – Possible Causes

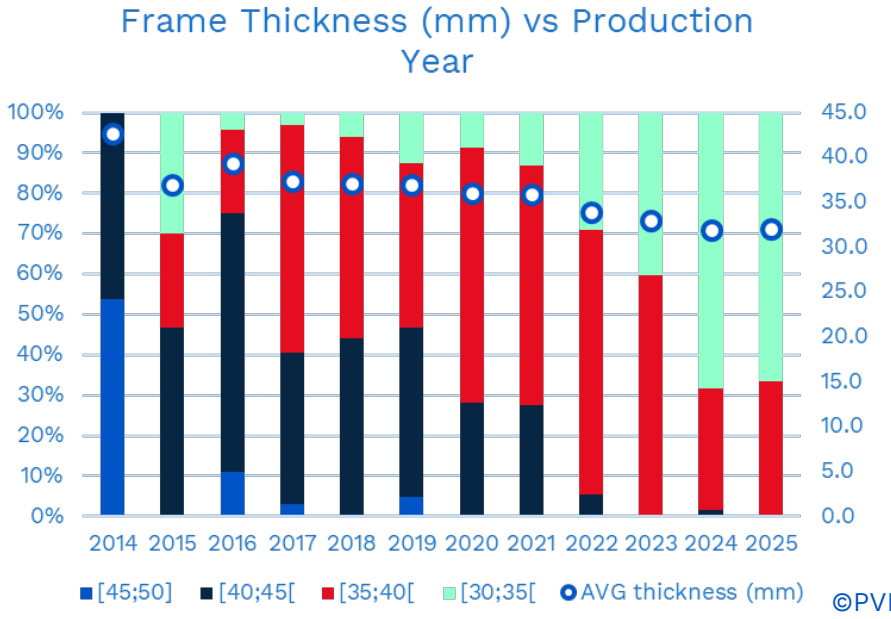
- Steep increase in SML and DML failure rates observed over the past 18 months.
- “Leading” failure mode appears to be glass breakage (front and/or rear) due to pinching.
  - Took over frame failures during 2024-2025 period

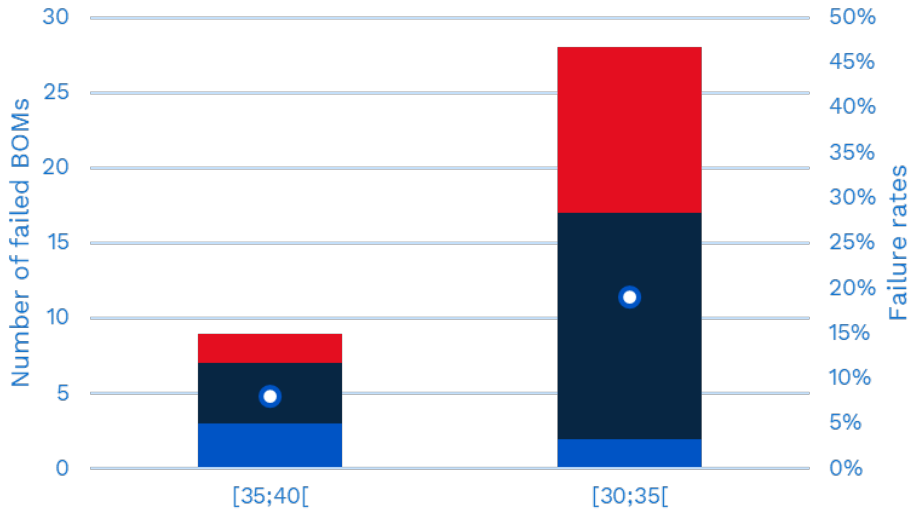


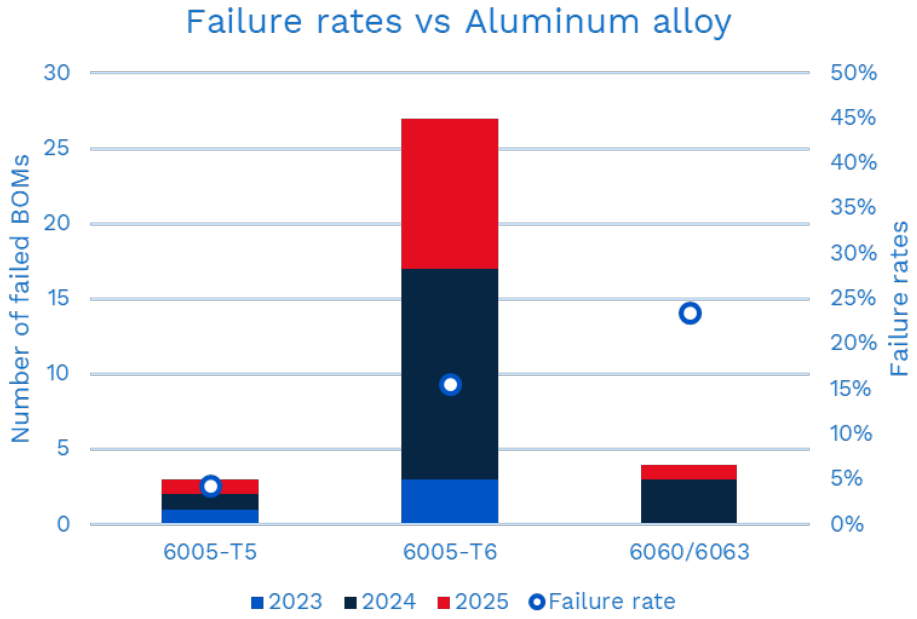
Until 2023: 2400Pa, 1/4 length clamp mounting
From 2024: 1800Pa, tracker 400mm mounting

#2 – Module Breakage – Possible Causes – Frame Design

- Frame thickness decreasing trends:
  - Average PQP frame thickness stable 2015 to 2021
  - **Strong acceleration in reduction of frame thickness from 2022** onwards (compounded decrease -12%)
  - Matching industry challenging situation (cost-down)
- Failure rate more than **doubled** when moving **from 35mm to 30mm** frame designs.
  - Transition to stronger 6005-T6 alloy did not help







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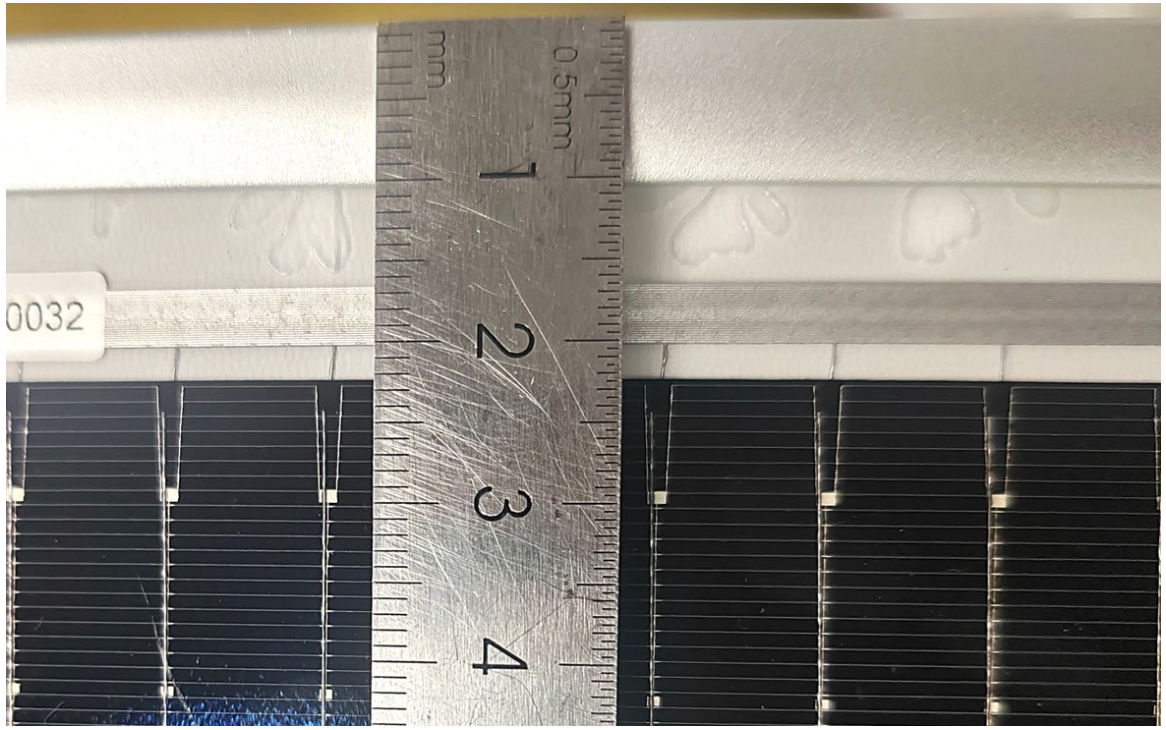
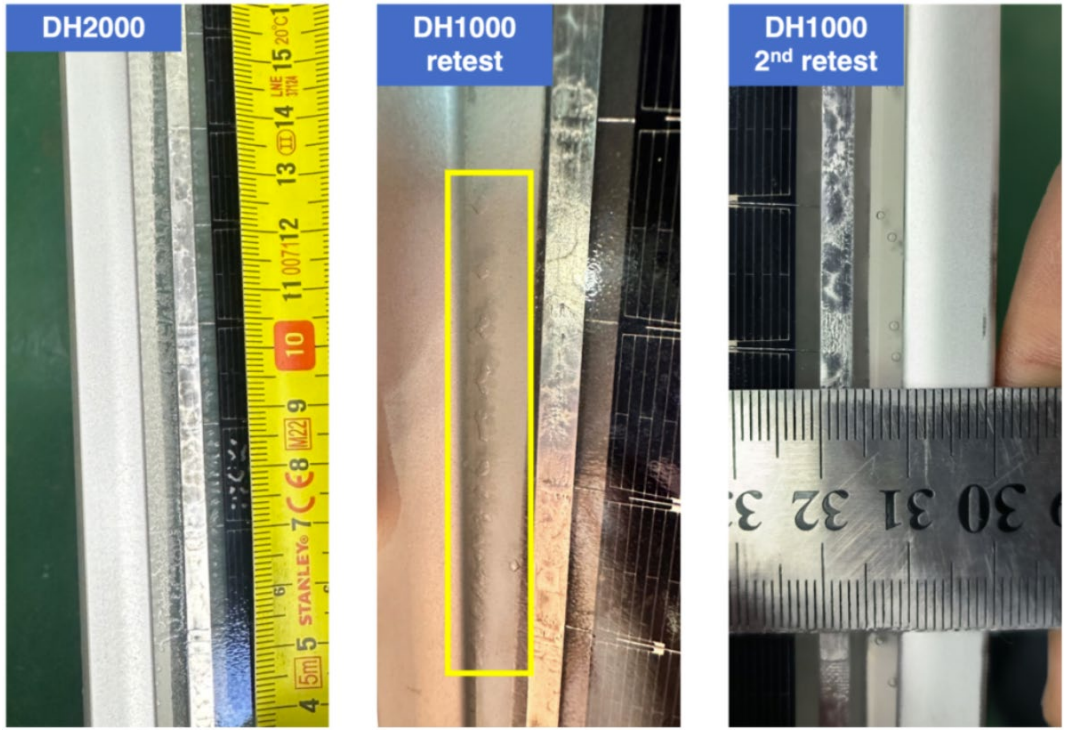
#1 – Delamination – Defects Continue to Increase



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



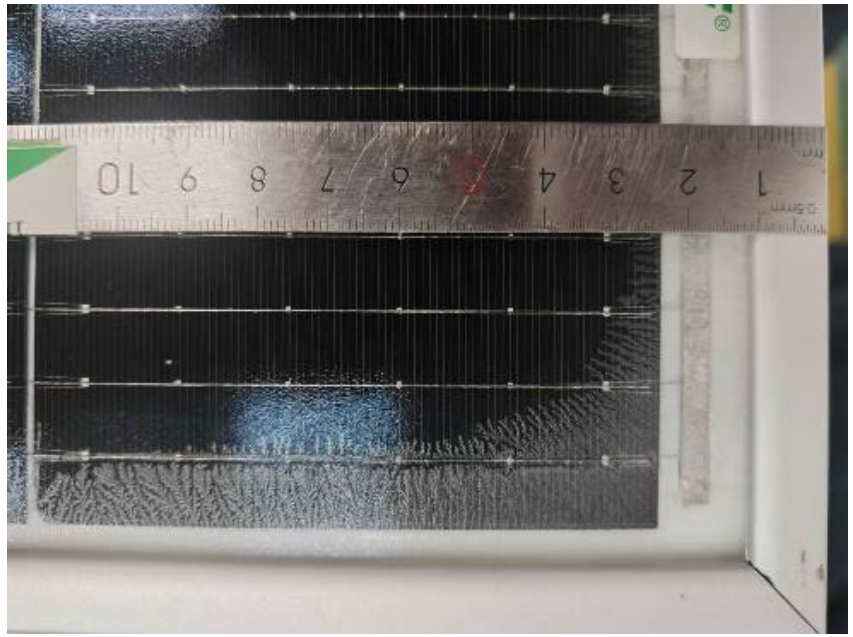
May 2024, PV Tech - *Outside the boxplot: Exploring Kiwa PVEL's PQP outliers*.

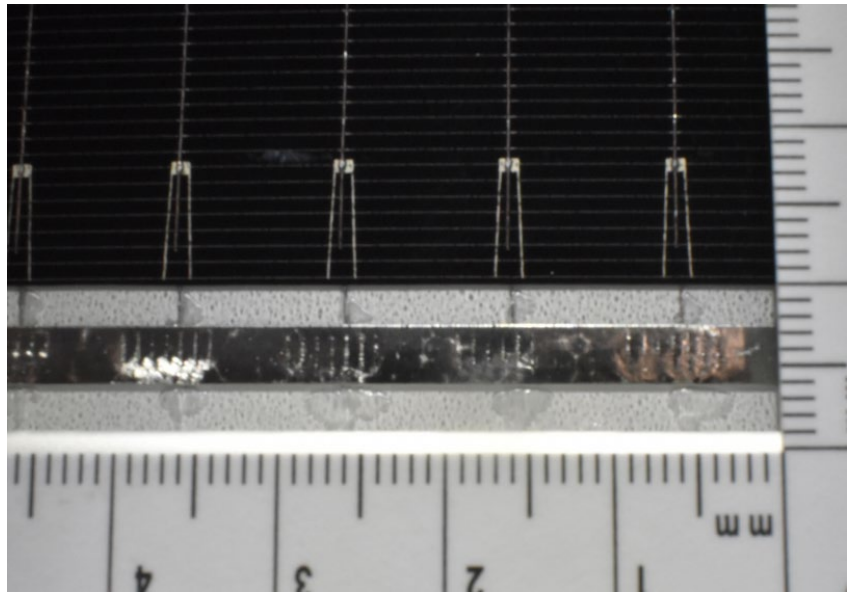
For 2025 Scorecard: Affected 15% of manufacturers.
Found at pre-stress, TC200 & 600, DH1000 & 2000, TC50+HF10, PID192.

#1 – Delamination – Defects Continue to Increase

- Significant increase of encapsulant delamination occurrences over 2025.
  - 143 unique BOMs tested over the 2024-2025 period
  - 108 samples with delamination or bubble defects reported
  - ~36% (52 BOMs) with at least one occurrence
  - Included **~11% (16 BOMs) with Major defects**
    - Cluster of bubbles or delamination forming a continuous path between electrical circuit and module edge
    - Failing creepage distance requirements from IEC61730-1
  - Mostly observed post-TC, DH, MSS testing

- Possible root causes, pending further analysis:
  - Reduced encapsulant thickness and dimensions
  - Lamination process control issues (lamination time, temp.)
  - Edge pinch
  - Improper solder flux recipe and/or residue cleaning





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 your attention!

Tristan Erion-Lorico

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Contact us:
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