



INSIGHTS ON RELIABILITY AND PERFORMANCE TESTING OF OVER 50 MODULE MANUFACTURERS

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Kiwa PVEL

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Kiwa PVEL is the Independent Lab of the Downstream Solar Market

10+

Years of
experience

600+

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.

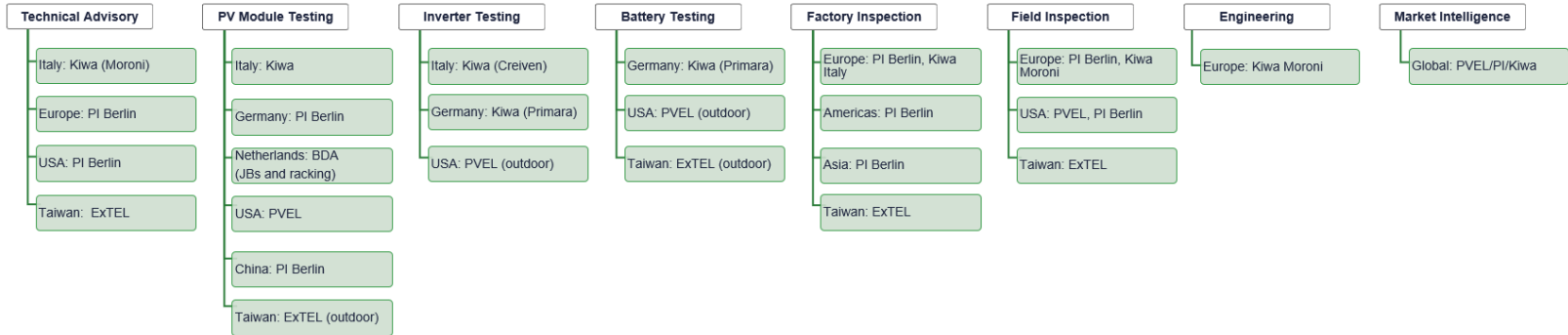
Services at a glance

- Extended reliability and performance testing for PV modules
- Batch testing of PV modules
- Outdoor testing at PVUSA, an iconic grid-connected research site
- 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 solar businesses at a glance:



- 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 PVEL PQP Introduction



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PV Module Product Qualification Program (PQP)

We launched our PQP in 2012 with two goals:

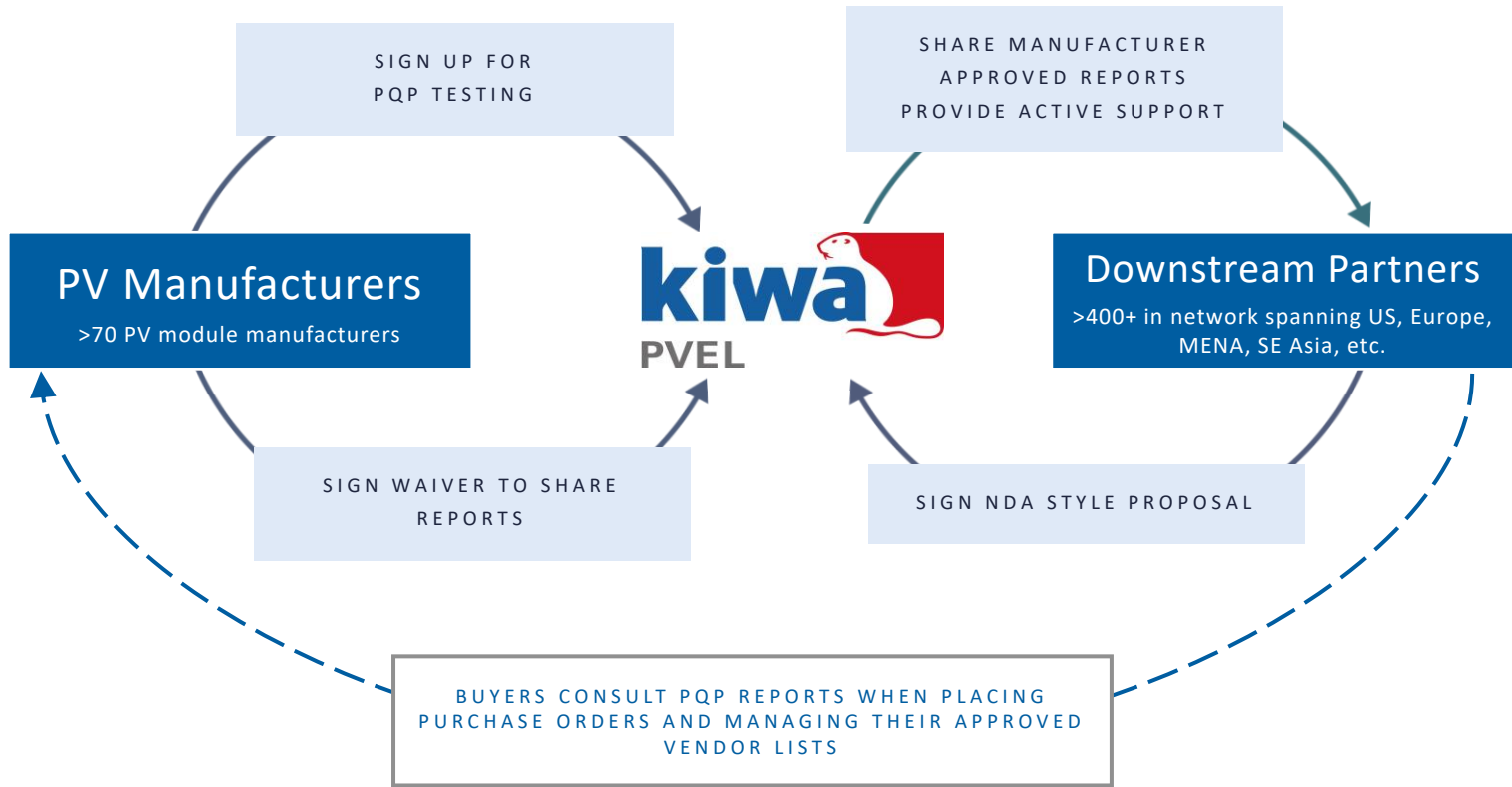
1. To provide independent reliability and performance data to PV module buyers.
2. To recognize manufacturers and products that excel in testing.

Our Process:

- Production of the PQP samples is factory witnessed by Kiwa PVEL's inspectors to record the detailed bill of materials (BOMs).
- Kiwa PVEL PQP testing is performed in California, USA and Suzhou, China.
- All PQP testing is overseen by Kiwa PVEL using industry best practices and calibrated equipment.

To date, we have tested over 600 PV module BOMs from 70+ module manufacturers in our PQP.

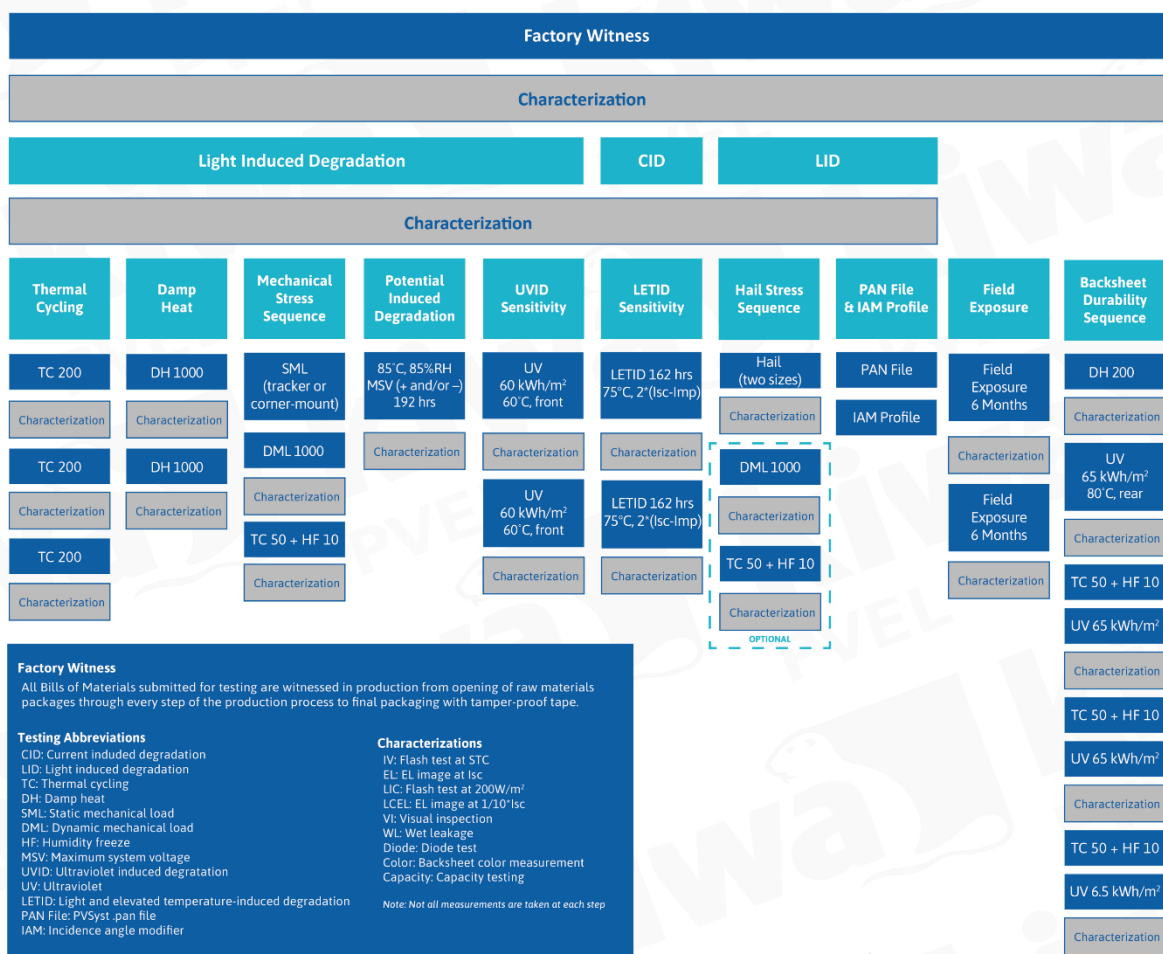
How Kiwa PVEL's PV Module PQP Works

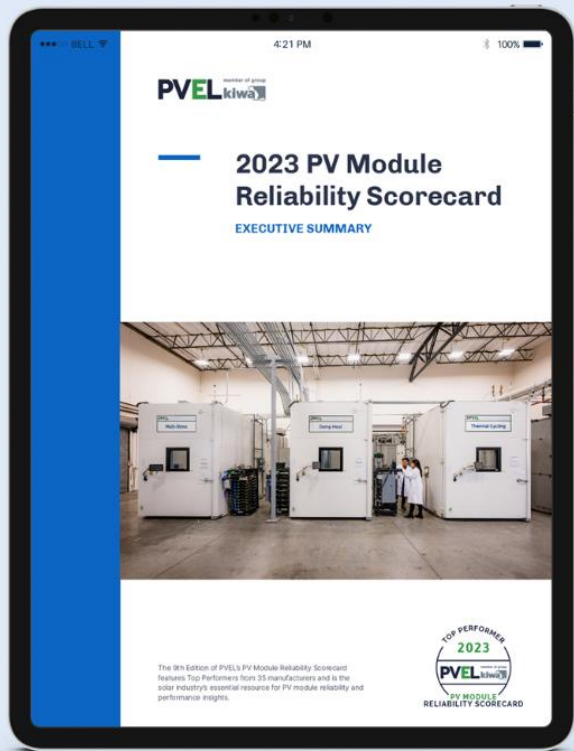


Kiwa PVEL PQP Test Sequence

These test streams evolve based on feedback from Kiwa PVEL's downstream partners, module manufacturers, and the industry's collective understanding of module failure modes and test mechanisms.

Learn more at kiwa.com/pvel/pqp





■ The 2024 PV Module Reliability Scorecard will be released on June 5, 2024.

■ To be eligible for the 2024 Scorecard, manufacturers must have:

- Completed the PQP sample production factory witness within 18 months of the Scorecard year.
- Submitted at least two factory-witnessed PV module samples to all PQP reliability tests, as per Kiwa PVEL's BOM test requirements

■ Top Performers in each of the reliability tests appearing in the Scorecard must have < **2% power degradation** following the particular test, and not have experienced a wet leakage failure, 'major' defect during visual inspection, or a diode failure for that particular testing.

■ PAN Performance Top Performers must place in the **top quartile for energy yield** in Kiwa PVEL's PVsyst simulations

Kiwa PVEL reserves the right to modify the Top Performer requirements at its sole discretion.

The annual PV Module Reliability Scorecards lists top performing manufacturers and insights from Kiwa PVEL's PQP. To date, the 2023 Scorecard has been accessed by more than **35,000 unique visitors** from over 160 countries.



Premium Partner Program

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Kiwa PVEL's Premium Partner Program – Dashboard

Achieve data-driven vendor management and identify PV modules that meet your reliability needs.

- Subscribers receive a quarterly Dashboard of Kiwa PVEL's **Product Qualification Program (PQP)** test results over a rolling period of 36-months. This allows for easy Approved Vendor List (AVL) management and identification of potential new suppliers.

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-48h)
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	Test not required	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	Test not required	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%

- PQP results from over 45 module manufacturers are included in the Dashboard, with nearly 30 manufacturers sharing their non-anonymized results. Nearly 200 BOMs are included, with over 60% of BOMs non-anonymized.
- Get direct access to detailed PQP test reports for all manufacturers who have agreed to share.

Kiwa PVEL's Premium Partner Program – Other Benefits

- Subscribers receive a comprehensive quarterly presentation including key insights from Kiwa PVEL's testing.

Recent Damp Heat Outlier

- Damp Heat
- DH 1000
- Characterization
- DH 1000
- Characterization
- Stabilization 85°C, 1h, 48 hrs
- Characterization

Power is darkening permitted (highest)

Trace on busbars

BOM vs EVA+ET more cc POE+PI encaps present

Power Loss: -4%

Recent PID Outlier

- Damp Heat
- DH 1000
- Characterization
- DH 1000
- Characterization
- Stabilization 85°C, 1h, 48 hrs
- Characterization

Feature 1 - bubbles

Feature 2 - bubbles

Feature 3 - pollution

Feature 4 - bubbles

Feature 5 - bubbles

PID mc exhibit loss >2 unusual

Expect recover UV exp

No sig results.

Hail Damage

- From PVEL's 50 mm, 32 m/s hail testing over the last year, glass/glass mods that survive the test almost never have cell cracks.
- Expect recover UV exp
- Of the ~10 glass/glass mods that survived PVEL's hail testing only ~1 had any cell cracks.
- Modules that survive the hail stress sequence with intact glass have a power loss of 1-3%.
- Some modules with cell cracks (see image, right) that appear after the hail test experience minimal power degradation

A 1.4% degradation

B 1.8% degradation

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- Kiwa PVEL holds quarterly 1:1 calls with each Premium Partner Program subscriber to discuss in-depth insights and provide feedback on procurement decisions.

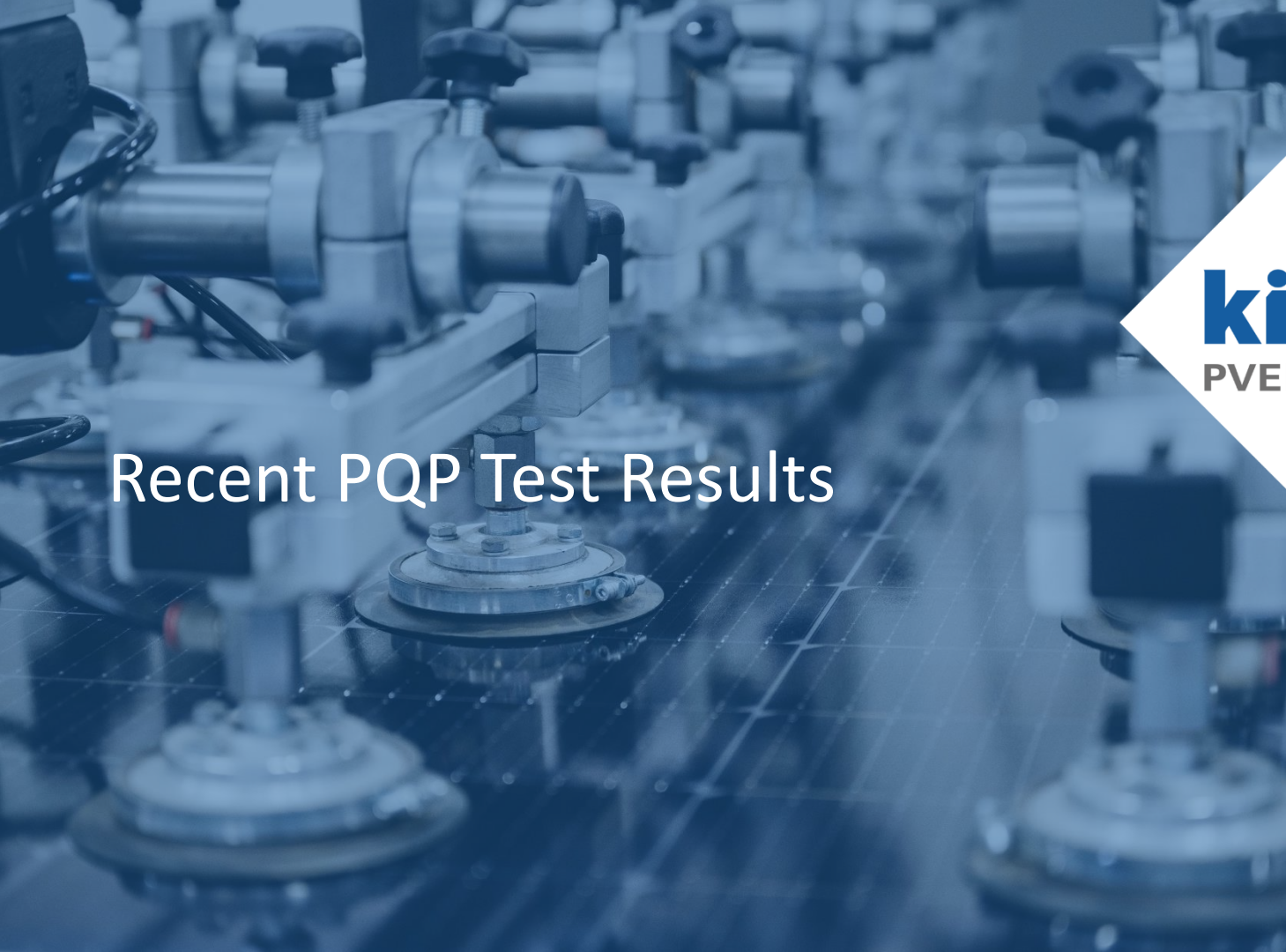
Kiwa PVEL's Premium Partner Program – Participants

■ A sample of manufacturers agreeing to share results in the Dashboard:



■ A sample of current Premium Partner Program subscribers:





Recent PQP Test Results

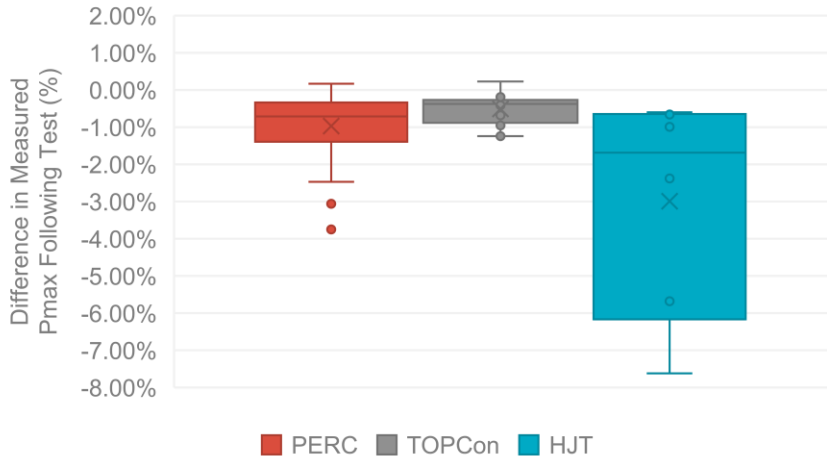


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Thermal Cycling Trends by Technology

- Thermal Cycling
- TC200
- Characterization
- TC200
- Characterization
- TC200
- Characterization

TC600 in mono PERC, TOPCon, and HJT modules, Q1 2021-Q1 2024



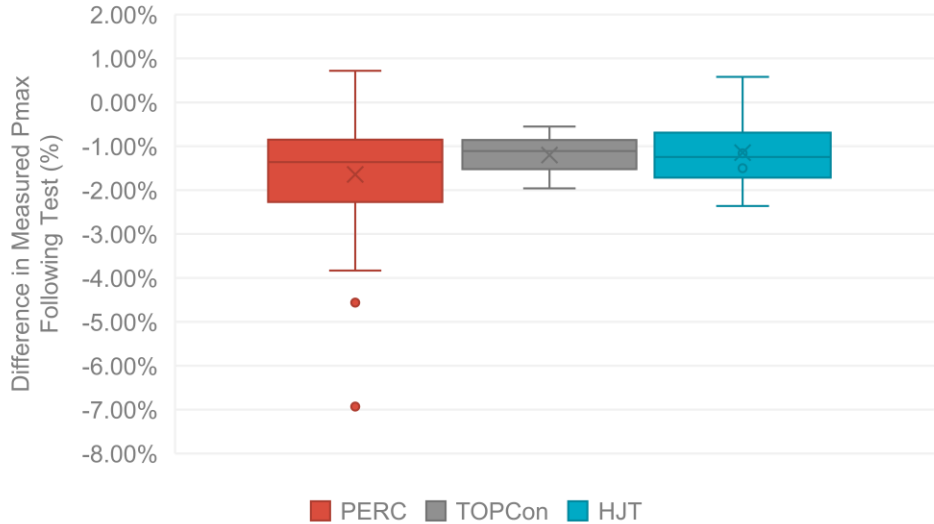
- The module is subjected to 600 cycles from -40°C to $+85^{\circ}\text{C}$.
- This test helps to identify cell soldering issues, among others.
- Mean degradation for PERC is -0.97% , -0.51% for TOPCon, and -2.99% for HJT.
- TOPCon and HJT results in several recent tests, have been significantly worse than those presented here.

	PERC	TOPCon	HJT
P10	-0.17%	-0.20%	-0.63%
P50	-0.71%	-0.38%	-1.69%
P90	-1.98%	-1.21%	-6.65%
P99	-3.67%	-1.24%	-7.52%
Count	68	12	6

Damp Heat Trends by Technology

- Damp Heat
- DH1000
- Characterization
- DH1000
- Characterization

DH2000/BO in mono PERC, TOPCon, and HJT modules, Q1 2021-Q1 2024



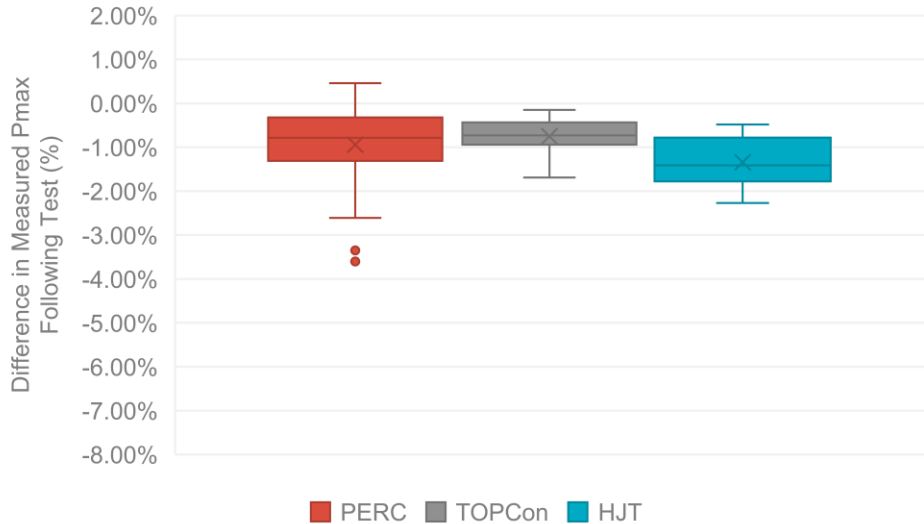
- The module is subjected to +85°C and 85% relative humidity for 2000 hours, followed by a 48-hour stabilization step.
- This test reveals corrosion and/or delamination in susceptible modules.
- TOPCon and HJT results in recent tests, have been significantly worse than those presented here.

	PERC	TOPCon	HJT
P10	-0.30%	-0.72%	-0.27%
P50	-1.36%	-1.11%	-1.25%
P90	-2.68%	-1.88%	-1.93%
P99	-7.75%	-1.95%	-2.32%
Count	80	16	6

Mechanical Stress Sequence Trends by Technology

- Mechanical Stress Sequence
- SML (tracker or corner mount)
- DML1000
- Characterization
- TC50 + HF10
- Characterization

MSS in mono PERC, TOPCon, and HJT modules, Q1 2021-Q1 2024

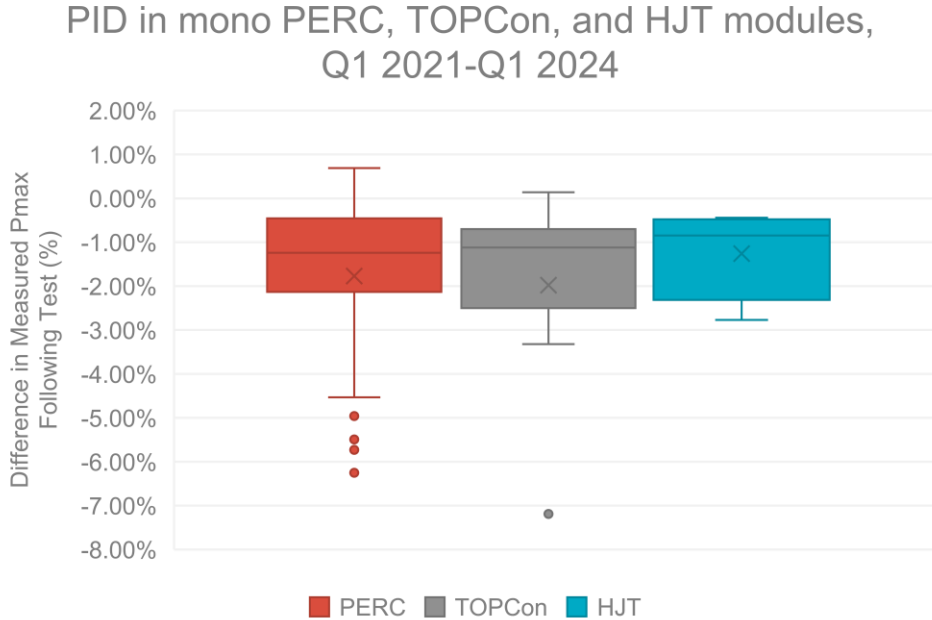


- SML includes 3 rounds of downward and upward force at 2,400 Pa. The subsequent DML test comprises 1,000 cycles of positive-negative loading at $\pm 1,000$ Pa. Then thermal cycling for 50 cycles and 10 humidity freeze cycles.
- This test reveals mechanical strength of the cell interface as well as the durability and rigidity of the PV module itself.

	PERC	TOPCon	HJT
P10	-0.10%	-0.27%	-0.68%
P50	-0.79%	-0.73%	-1.41%
P90	-2.06%	-1.33%	-1.94%
P99	-3.36%	-1.63%	-2.24%
Count	98	33	6

Potential Induced Degradation Trends by Technology

- Potential Induced Degradation
- 85°C, 85% RH
MSV (+ and -)
192 hours
- Characterization

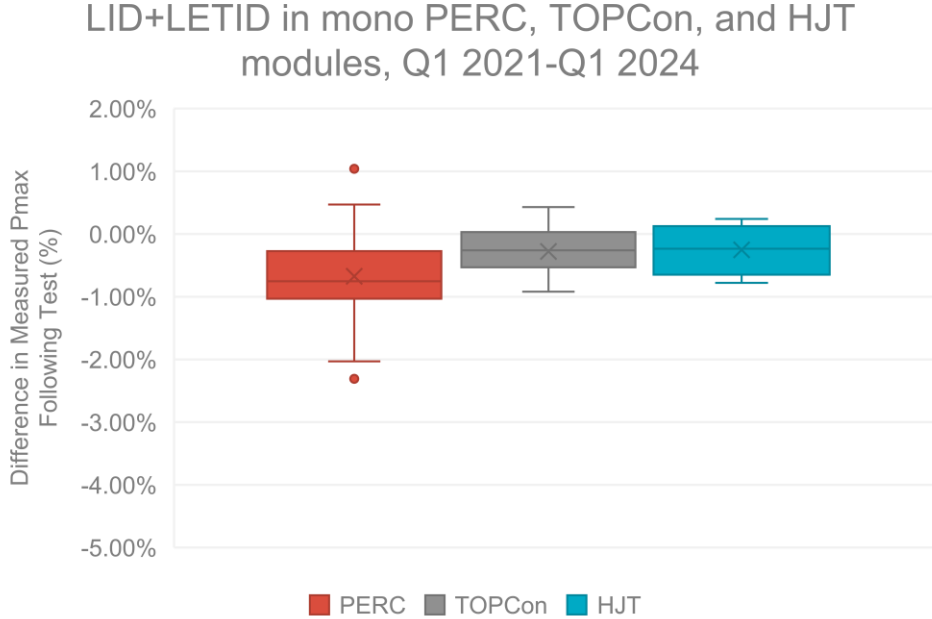


- The module is subjected to +85°C, 85% relative humidity and maximum system voltage bias between the cells and frame for 192 hours.
- Some modules are showing recovery after IEC 61215 2kWh/m² UV exposure, although the field relevancy of the degradation and/or recovery is not certain.

	PERC	TOPCon	HJT
P10	-0.13%	-0.58%	-0.47%
P50	-1.24%	-1.12%	-0.85%
P90	-4.53%	-3.18%	-2.47%
P99	-8.78%	-11.56%	-2.74%
Count	81	31	6

LID + LETID Trends by Technology

- LID
- Light Soaking
≥ 40 kWh/m²
- Characterization
- LETID
Sensitivity
- LETID 162 hrs
75°C, 2* (I_{sc}- I_{mp})
- Characterization
- LETID 162 hrs
75°C, 2* (I_{sc}- I_{mp})
- Characterization



- LID: 17 modules exposed outdoor to several rounds of light-soak and flash test until stability.
- LETID: 2 post-LID modules are subjected to 75°C with a low current injected for 486 hours.
- Very little LID or LETID seen in gallium-doped PERC and n-type modules, although UVID susceptibility is a concern.

	PERC	TOPCon	HJT
P10	0.12%	0.17%	0.10%
P50	-0.75%	-0.26%	-0.24%
P90	-1.40%	-0.68%	-0.62%
P99	-2.13%	-0.89%	-0.76%
Count	64	19	4



Other Kiwa PVEL Reports

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Also available: Solar Technology and Cost Report

CRU Solar Technology and Cost Report

exawatt **PVEL** member of group **kiwa**

Manufacturers continue to be squeezed by falling spot prices

With module inventories outside of China growing, and with limited optimism from many manufacturers for Q1 2024, module prices look set to remain low. Module buyers should be conscious that many suppliers will be under financial pressure during 2024, with a risk of bankruptcies and of cost-cutting using lower-quality input materials

Q1 2024 | January 2024

CRU/Exawatt and Kiwa PVEL publish the quarterly **Solar Technology and Cost report (STAC)**, covering market, technology and cost outlooks for PV module technologies.

To find out more, please go to kiwa.com/pvel/stac

Also available: Solar Technology and Cost Report

 Energy Storage Technology and Cost Service

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Growth of renewables and dropping lithium prices are accelerating Battery Energy Stationary Storage (BESS) demand

The transition to renewable energy is driving unprecedented demand for energy storage, specifically for BESS. Falling lithium prices across 2023 have pushed LIB prices even lower, speeding the uptake of LIB BESS

2024 Q1 | 2024 January

CRU/Exawatt and Kiwa PVEL publish the quarterly **Energy Storage Technology and Cost report (ESTAC)**, covering market, technology and cost outlooks for battery storage technologies.

To find out more, please go to kiwa.com/pvel/estac



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