



The 2026 PV Module *Reliability Scorecard*



Executive Summary

kiwa

The 12th Edition of Kiwa PVEL's PV Module Reliability Scorecard features the latest insights in module reliability and performance and this year's list of Top Performers.

Table of Contents

Welcome Message	3
Methodology	4
Kiwa PVEL's PV Module PQP	5
Thermal Cycling	6
Damp Heat	7
Mechanical Stress Sequence	8
Hail Stress Sequence	9
Potential Induced Degradation	10
LID + LETID	11
Ultraviolet Induced Degradation	12
PAN Performance	13
Incidence Angle Modifier	14
Backsheet Durability Sequence	15
PQP Failures	16
Historical Scorecard	17
Top Performers Per Test	18
About Us	19

Welcome to Kiwa PVEL's 2026 Scorecard *Executive Summary*

Kiwa PVEL's Product Qualification Program (PQP) and Scorecard are the global solar industry's trusted resources for PV module reliability and performance data. In this 12th edition of the Scorecard, Kiwa PVEL is proud to once again showcase a broad range of Top Performer manufacturers and module model types.

The 2026 Scorecard also features new Key Takeaways and Test Result Spotlights, providing insights on the industry's most important reliability topics, including module breakage, UVID, delamination and more.

As always, the Scorecard provides key insights, but managing the complexities of module procurement requires careful consideration. Reviewing the full PQP test reports and specifying top performing bills of materials (BOMs) are critical aspects of Kiwa Solar's procurement best practices. Achieve more informed and effective module sourcing by becoming a Kiwa PVEL Premium Partner.

Learn more at kiwa.com/pvel/ppp.

Executive Summary Contents

This Executive Summary offers readers a brief overview of Kiwa PVEL's PQP methodology and how BOMs are scored. Key takeaways from each of the PQP tests are also included, which provide an overview of the latest test findings and trends. The Historical Scorecard is also presented, showing all of the 2026 Top Performer manufacturers and their history of Scorecard appearances, as well as the Top Performers Per Test table showing for which tests each manufacturer achieved Top Performer status.

Scorecard Website Contents

scorecard.pvel.com provides much more than the Executive Summary, including:

- A searchable database of Top Performer model types, which can be filtered by PQP test, manufacturer name, module power class and more. Search results are exportable as CSV files.
- Test result spotlights for each test, highlighting a recent finding or trend.
- Graphs of yearly power degradation for most tests and additional details on key takeaways.
- Pages dedicated to all sections shown in the Executive Summary.
- Direct links to test-specific pages on kiwa.com for field case studies, test procedures and more.

Methodology

Since 2012, Kiwa PVEL's Product Qualification Program has focused on benchmarking PV module reliability and performance. Our PQP reports and results support informed solar procurement and investment decisions.

Why BOM-Level testing is important

PV modules with the exact same model type can be manufactured from completely different bills of materials (BOMs). Changes in PV module components can have big impacts on reliability and performance, and the industry's certification tests are typically not rigorous enough to identify these potential issues. Module warranties also often have shortcomings that leave site owners exposed to significant financial losses. Kiwa PVEL's PV Module PQP is a comprehensive protocol of tests focused on addressing these concerns and helping module buyers achieve better procurement.

Scorecard Eligibility

To be eligible for the 2026 Scorecard, manufacturers must have:

- Completed the PQP sample production factory witness after November 1, 2024, and, for each BOM shown, have at least one new Top Performer-achieving result that was not included in the 2025 Scorecard.
- Submitted at least two factory-witnessed PV module samples to all PQP reliability tests, as per Kiwa PVEL's BOM test requirements.

How BOMs are Scored

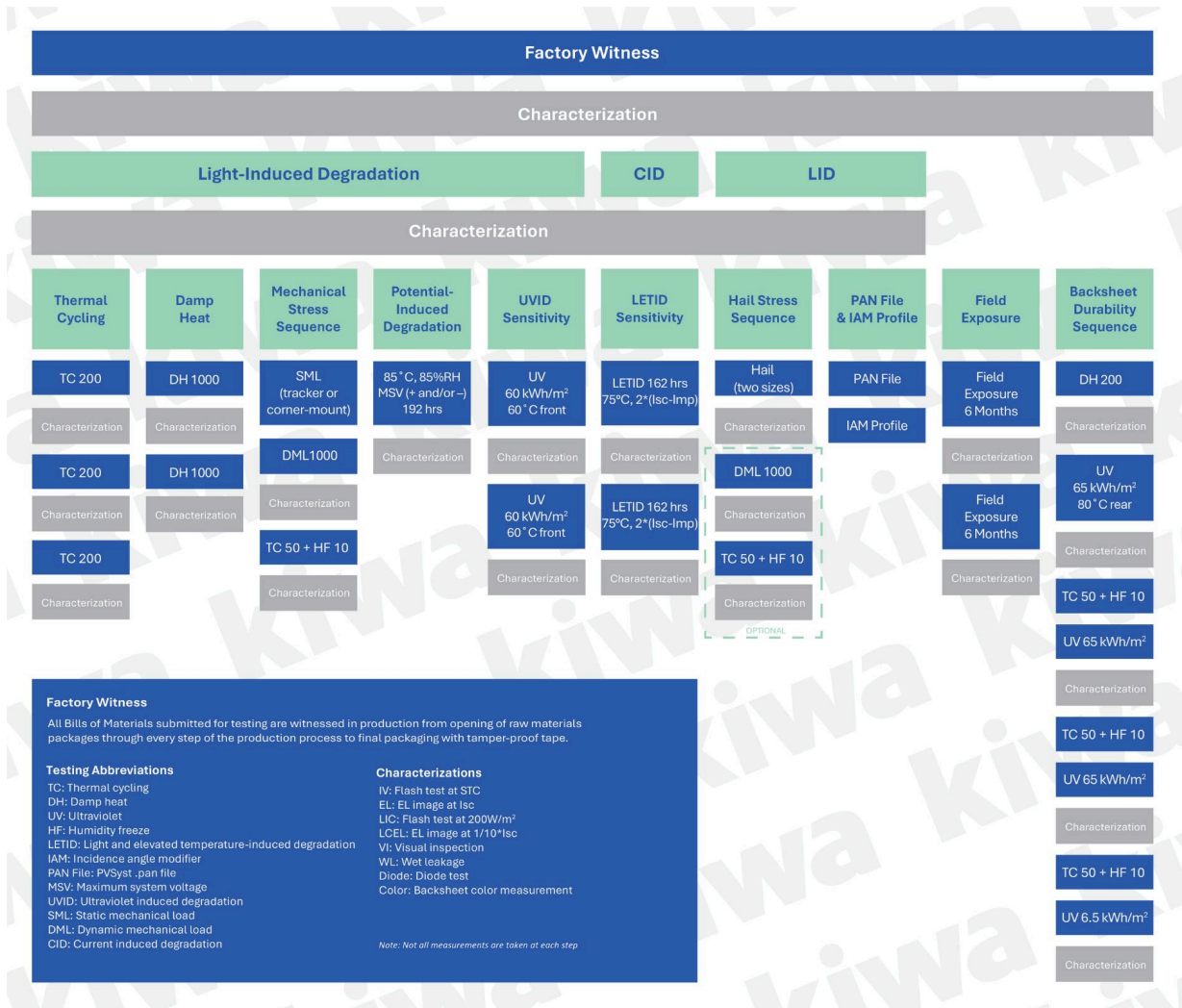
The 2026 PV Module Reliability Scorecard lists Top Performers for eight PQP test categories, including UVID as a brand new Top Performer test. To be listed as a Top Performer in a particular test, the modules must not have experienced a wet leakage failure, a 'major' defect during visual inspection or a diode failure during that particular test.

- Top Performers for TC, DH, MSS, PID and UVID must have <2% power degradation. For MSS, the mounting used during mechanical load testing is shown in the Top Performer list. For PID, the BOM must have <2% power degradation in PID(+) and PID(-).
- Top Performers for HSS must not have experienced glass breakage during hail testing using 40 mm hail or larger. The actual hail size is shown in the Top Performer list, as well as the BOM glass thickness.
- Top Performers for LID + LETID must have <1% power degradation when combining the LID and LETID test results.
- Top Performers for PAN performance must place in the top quartile for energy yield in Kiwa PVEL's PVsyst simulations. That BOM's IAM results are also included in the PAN analysis.

In some cases, test results for some test categories were not available at the time of Scorecard publication. Kiwa PVEL's Premium Partners access the detailed PQP results on a quarterly basis rather than waiting for the next Scorecard. Find out more about subscribing at kiwa.com/pvel/ppp.



Kiwa PVEL's PV Module PQP



The above test plan was used for all BOMs represented in the 2026 Scorecard. However, the updated PQP test plan was released in April 2026. More details on that can be found at kiwa.com/pvel/pqp12.

2026 Scorecard – Key Takeaways

- 43 manufacturers are included in the 2026 Scorecard as Top Performers. 15 of them have at least one model type listed as a Top Performer in at least seven of eight tests.
- Only 5 models achieved Top Performer status in all reliability tests (TC, DH, MSS, HSS, PID, UVID and LID+LETID). Of those, none were Top Performers in those tests plus PAN performance.
- PID and UVID power loss reduced, PAN energy yields increased, power loss following MSS and HSS continues to be minimal and the percentage of BOMs with <2% degradation increased for TC and DH. However, the percentage of BOMs with <2% degradation decreased for LID+LETID, and PQP failures are concerningly high.
- 87% of module manufacturers and 61% of BOMs had at least one test failure, up from the 83% and 59% reported in the 2025 Scorecard, respectively.

Thermal Cycling

The PQP's Thermal Cycling (TC) test extends the IEC/UL certification test from 200 to 600 cycles, more accurately simulating a PV module's lifespan of temperature fluctuations. TC's extreme temperature swings stress module components, degrading interfacial bonds within the module and junction box that could substantially reduce performance. This test is crucial for environments with significant day-to-night temperature differences.



Thermal Cycling Key Takeaways

- 83% of BOMs tested degraded by <2% following TC600. This has increased from 71% of BOMs degrading by <2% reported in the 2025 Scorecard.
- 37% of TC BOMs experienced at least one failure during TC testing, which is a record high failure rate. These failures included delamination, failed bypass diodes, safety failures and more.
- Reducing encapsulant thickness raises reliability risks. For example, >70% of BOMs with >2% power loss following TC600 used front encapsulant with area weight in the lower quartile range ($\leq 400 \text{ g/m}^2$).
- Busbar-free technology (also known as OBB or ZBB) eliminates the busbars on solar cells, reducing silver consumption and boosting module efficiency. But ZBB BOMs have a wider range of TC power loss versus BOMs utilizing traditional cell busbars.

Go to scorecard.pvel.com/TC to see more.



Damp Heat

The PQP's Damp Heat (DH) test is 2000 hours, double the duration of the IEC/UL certification test. For susceptible modules, this test instigates long-term degradation and failure modes that are typical in high temperatures and high humidity conditions where moisture and heat can weaken the materials binding the module together.

Damp Heat Key Takeaways

- 69% of BOMs tested degraded by <2% following DH2000. The median degradation for DH BOMs produced in 2025 was 1.7% compared to 1.8% for BOMs produced in 2024.
- 32% of BOMs experienced at least one DH failure. These include 23% of BOMs experiencing a delamination failure, a shockingly high defect rate.
- Most delamination failures following DH occurred on BOMs with relatively thick encapsulant. However, BOMs using front EPE or POE had a higher rate of both major and minor delamination occurrences versus those using front EVA.
- Kiwa PVEL has observed a correlation with BOMs using narrower encapsulants having a higher likelihood of delamination failures than BOMs where the encapsulant width exceeds the glass width.

Go to scorecard.pvel.com/DH to see more.



Mechanical Stress Sequence

The PQP's Mechanical Stress Sequence (MSS) surpasses IEC/UL certification for more thorough module and cell durability testing. It detects potential glass and cell cracking vulnerabilities, and frame structural weaknesses through static and dynamic load testing. This test further assesses power output reduction due to cell cracks, crucial for sites facing extreme weather such as heavy snow and high winds.

MSS Key Takeaways

- 100% of BOMs completing MSS had <2% power loss. Both the median and average post-MSS power loss were 0.8%, indicating that failures are the key aspect of MSS rather than potential power loss.
- 30% of BOMs experienced one or more failures during MSS testing, including 26% of MSS BOMs experiencing at least one broken module and 3% of MSS BOMs experiencing a delamination failure.
- 62% of broken modules in MSS showed evidence of pinched glass via front glass breakage. There are complex interactions across the frame, silicone sealant and glass, with this failure mode influenced by frame design, glass strength and potential contact between the glass and frame.
- For modules that are 2.5-3.0 m², the module breakage rate increased from 6.9% when using frames that are ≥35 mm to 17.9% when using frames that are <35 mm.

Go to scorecard.pvel.com/MSS to see more.



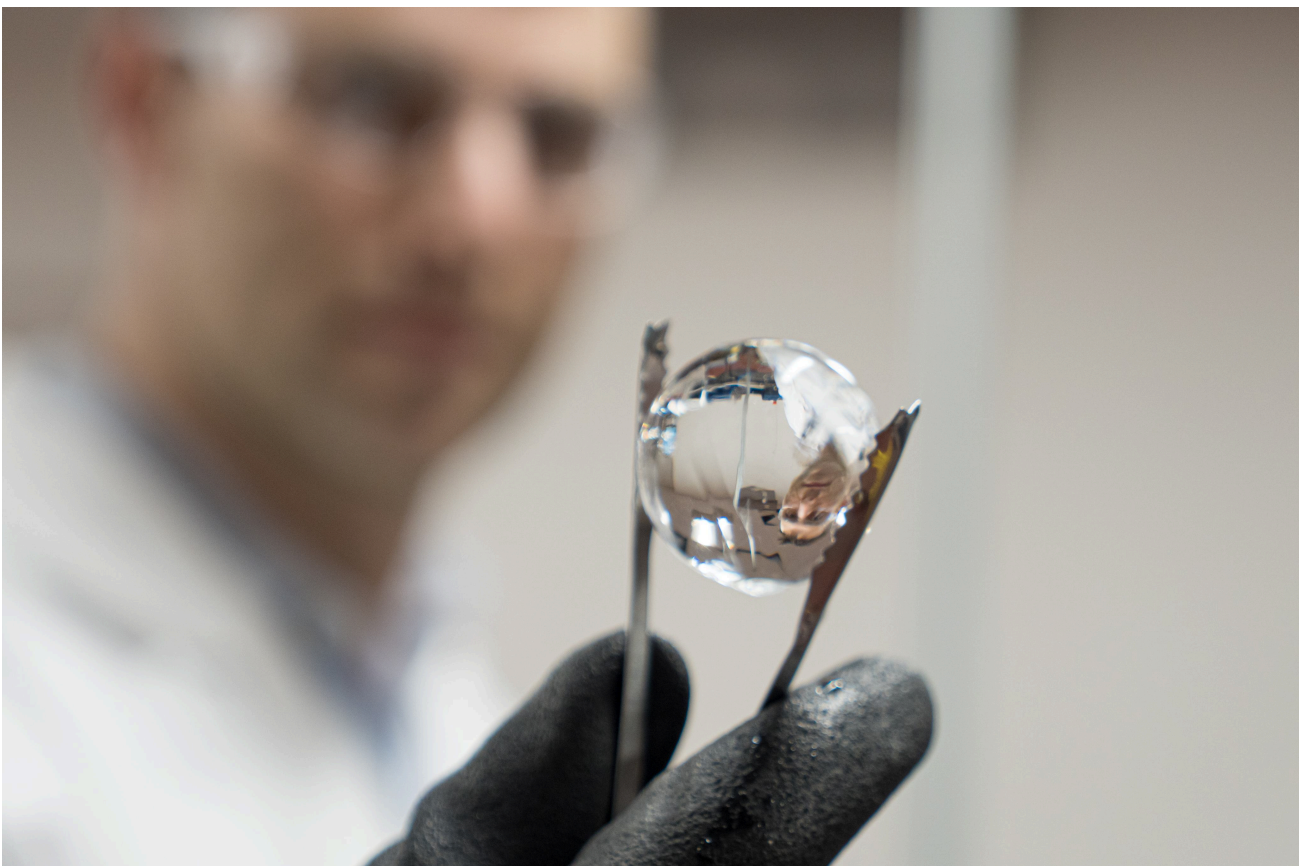
Hail Stress Sequence

The PQP's Hail Stress Sequence (HSS) surpasses IEC/UL minimum hail requirements to rigorously test PV modules with ice balls ranging in size from 35 to 55 mm, while ensuring consistent and comparable impact energies. This test is mostly focused on glass breakage but also provides insights on cell crack susceptibility.

HSS Key Takeaways

- The breakage rate of 'standard modules' (with 2.0 mm glass//2.0 mm glass) from 45 mm and 40 mm hail is 61% and 43%, respectively. The glass near the module edges and holes drilled for the junction boxes is more likely to break than glass in the center of the modules.
- Only 7% of 'thicker glass modules' break from 45 mm hail, proving again that 'thicker glass' modules (including 3.2 mm glass//backsheet, 2.5 mm glass//2.5 mm glass and 3.2 mm glass//2.0 mm glass) are significantly less susceptible to glass breakage than standard modules.
- 100% of HSS tested BOMs had <2% power loss. Glass//glass modules protect the cell from cracking within the neutral plane, and branching cell cracks in glass//backsheet modules suffer relatively little hail-induced power loss due to the use of half-cut, multi-bus bar (MBB) cells.
- 23% of BOMs experienced a failure, defined here as when there are broken modules from both hail sizes, or when the manufacturer requests a hail retest.

Go to scorecard.pvel.com/HSS to see more.



Potential Induced *Degradation*

The PQP's Potential Induced Degradation (PID) test doubles the IEC/UL certification test duration to 192 hours. There are multiple forms of PID. PID-shunting occurs when sodium ions from the glass travel to pinholes in the anti-reflective coatings on the cells, permanently lowering performance. PID-polarity is static charge build-up due to internal circuit voltages and is possibly reversible.

PID *Key Takeaways*

- 83% of BOMs produced in 2025 degraded by <2% following PID(-). This is an increase from the 72% of BOMs produced in 2024 that degraded by <2%. The median degradation following PID(-) was 1.1%.
- 15% of BOMs experienced a failure during PID testing. This included 6% of PID BOMs experiencing a power loss failure, 5% of PID BOMs experiencing a delamination failure and 2% of PID BOMs experiencing a safety failure.
- Five out of the six BOMs with PID power loss failures were affected by PID-polarization. While this degradation is typically reversible following a short UV exposure, there have been reports of PID-polarization occurring in the field under certain site conditions.
- There was only one BOM in the 2026 Scorecard dataset with <2% degradation for PID(-) and $\geq 2\%$ degradation for PID(+). Conversely, 18% of BOMs with <2% degradation for PID(+) had $\geq 2\%$ degradation following PID(-).

Go to scorecard.pvel.com/PID to see more.



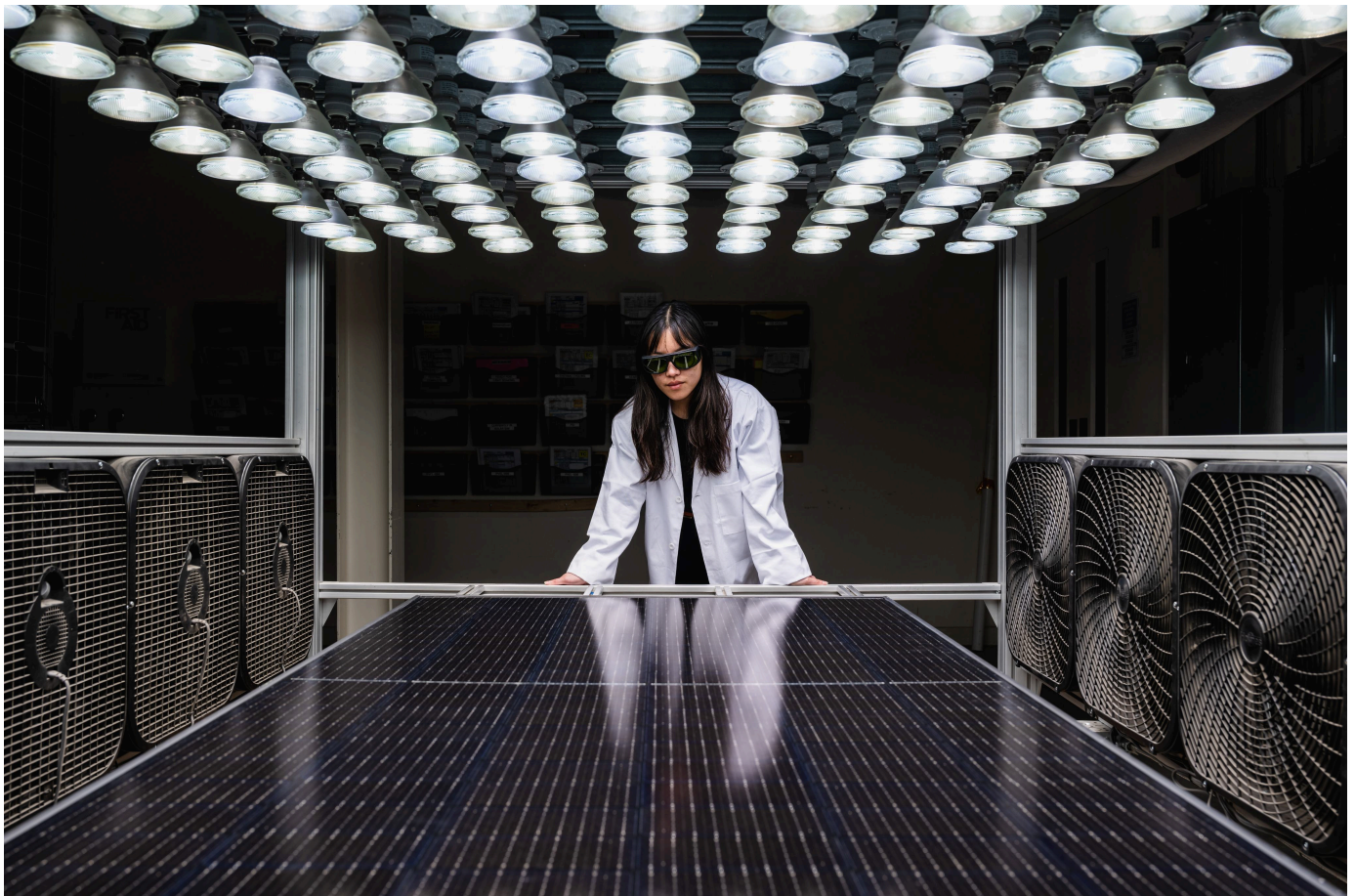
LID + *LETID*

The PQP's Light Induced Degradation (LID) and Light and Elevated Temperature Induced Degradation (LETID) tests quantify these cell-based phenomena that are often incorporated into energy yield models. LID varies by cell technology but primarily impacts boron-doped cells and stabilizes shortly after module deployment. Degradation from LETID reaches its maximum point after months or years.

LID + LETID *Key Takeaways*

- 79% of BOMs tested had <1% power loss in the combined LID plus LETID, with the median and average results slightly increasing for BOMs produced in 2025 versus 2024. New cell factories may explain this change.
- 13% of BOMs experienced at least one initial, LID and/or LETID failure, including 6% of BOMs experiencing a delamination failure during initial characterizations.
- The median LID power loss for 2026 Scorecard eligible BOMs was 0.4% for TOPCon, 0.6% for PERC, 0.7% for HJT and 0.6% for xBC; however, the HJT and xBC sample size was quite low.
- The median LETID power loss for 2026 Scorecard eligible BOMs was 0.1% for TOPCon, 0.1% for PERC, 0.4% for HJT and 0.1% for xBC; however, the maximum LETID power loss was 1.4% for one TOPCon BOM, signifying that this failure mode has not been completely eliminated.

Go to scorecard.pvel.com/LIDLETID to see more.



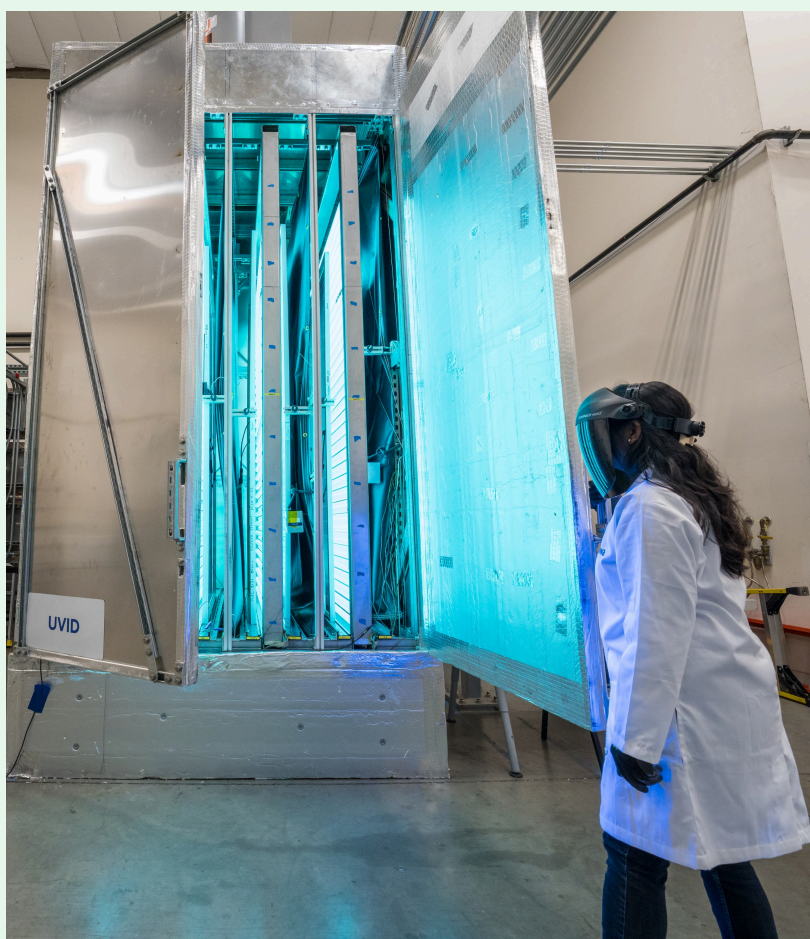
Ultraviolet Induced *Degradation*

Kiwa PVEL's Ultraviolet Induced Degradation (UVID) test goes beyond standard IEC/UL certification to identify modules that are susceptible to this degradation mechanism. While the 120 kWh/m² test duration is not necessarily sufficient to reach the maximum amount of degradation resulting from UVID, this test is able to distinguish between UVID-susceptible and UV-stable modules.

UVID *Key Takeaways*

- Kiwa PVEL has observed improved UVID performance in TOPCon BOMs, with median power loss reduced from 4.2% to 3.0%. This may be attributed to improved process and quality control at cell production facilities; however, UVID remains a challenge for some manufacturers.
- As the median UVID power loss has reduced over the past year, so has the percentage of BOMs experiencing a UVID failure, which decreased from 6% in the 2025 Scorecard to 3%.
- The PQP's optional Field Exposure test has identified some BOMs with significant degradation (median: 2%, maximum: 8%) following one year of deployment in Davis, CA. This has been mainly attributed to UVID.
- Both TOPCon and HJT modules exhibit dark storage degradation after test completion; however, the effect is more pronounced in UVID-sensitive TOPCon modules, with degradation rates up to 1% power loss per day.

Go to scorecard.pvel.com/UVID to see more.



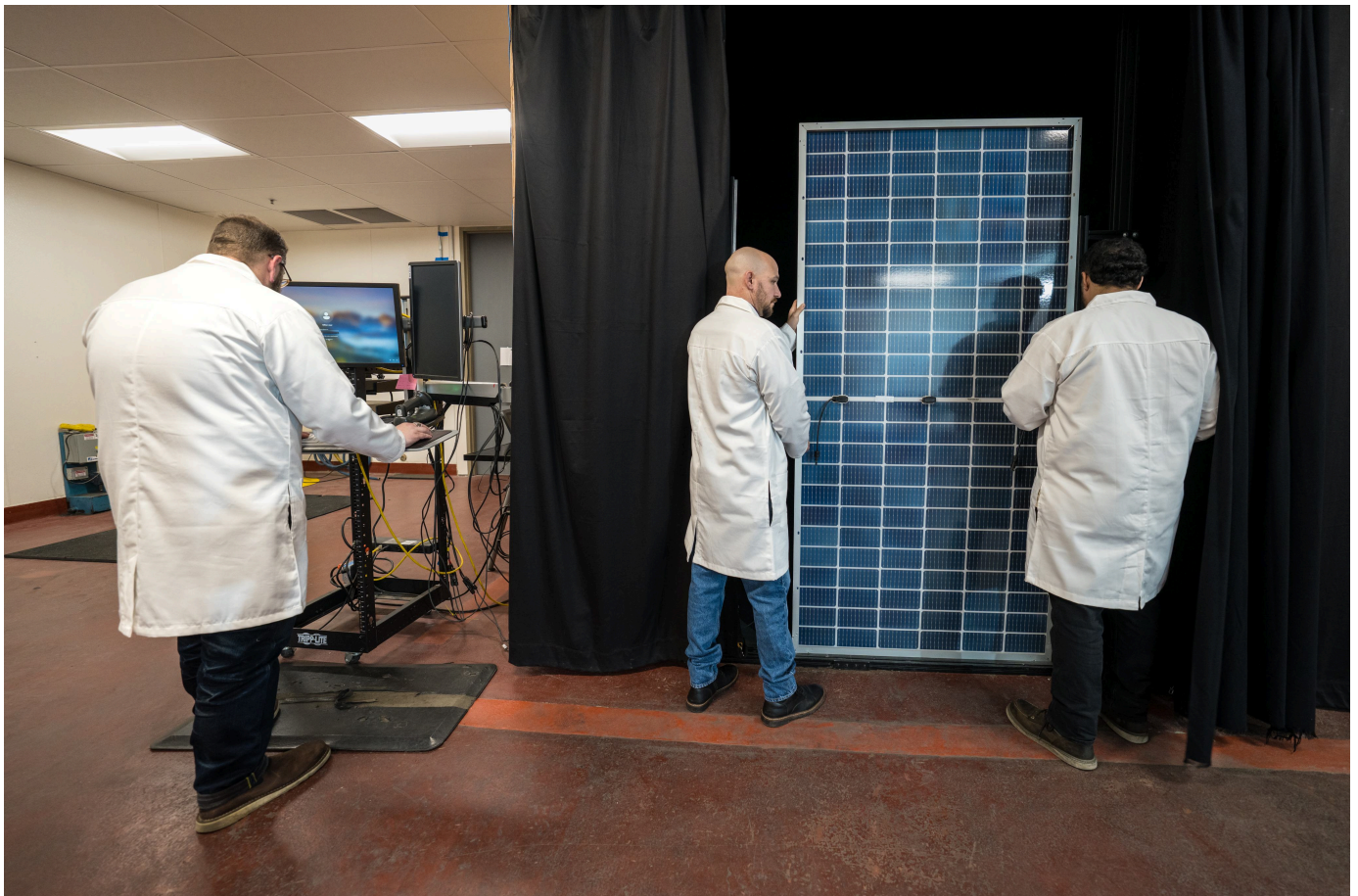
PAN Performance

Kiwa PVEL's PAN testing and .pan file generation enhances PV module performance simulations by using empirical data across a range of temperature and irradiance conditions. This is an essential input for accurate energy models, reflecting real-world conditions more accurately and supporting better decision-making in module procurement and project development.

PAN Performance *Key Takeaways*

- Energy yields improved by 0.34% and 0.53% for Kiwa PVEL's modelled sites in Las Vegas and Boston, respectively (or 0.43% average). This was due to an another increase in TOPCon BOMs being tested versus previous years.
- The median TOPCon Pmp temperature coefficient over the past three years improved slightly, from $-0.30\%/^{\circ}\text{C}$ to $-0.29\%/^{\circ}\text{C}$. This is still behind xBC's and HJT's median Pmp temperature coefficients (of $-0.27\%/^{\circ}\text{C}$ and $-0.26\%/^{\circ}\text{C}$, respectively), but better than PERC's (at $-0.32\%/^{\circ}\text{C}$).
- The median bifaciality over the past three years was 70.2% for PERC, 70.8% for xBC, 76.5% for TOPCon and 86.2% for HJT. TOPCon bifaciality is expected to increase over the coming year as more manufacturers implement poly-finger cell designs.
- The ranges in low light performance (as measured via the relative efficiency deviation at 200 W/m^2 compared to 1000 W/m^2) remain fairly aligned across technologies. The median low light performance was -5.4% for xBC, -3.8% of TOPCon, -3.6% for HJT and -3.5% for PERC.

Go to scorecard.pvel.com/PAN to see more.



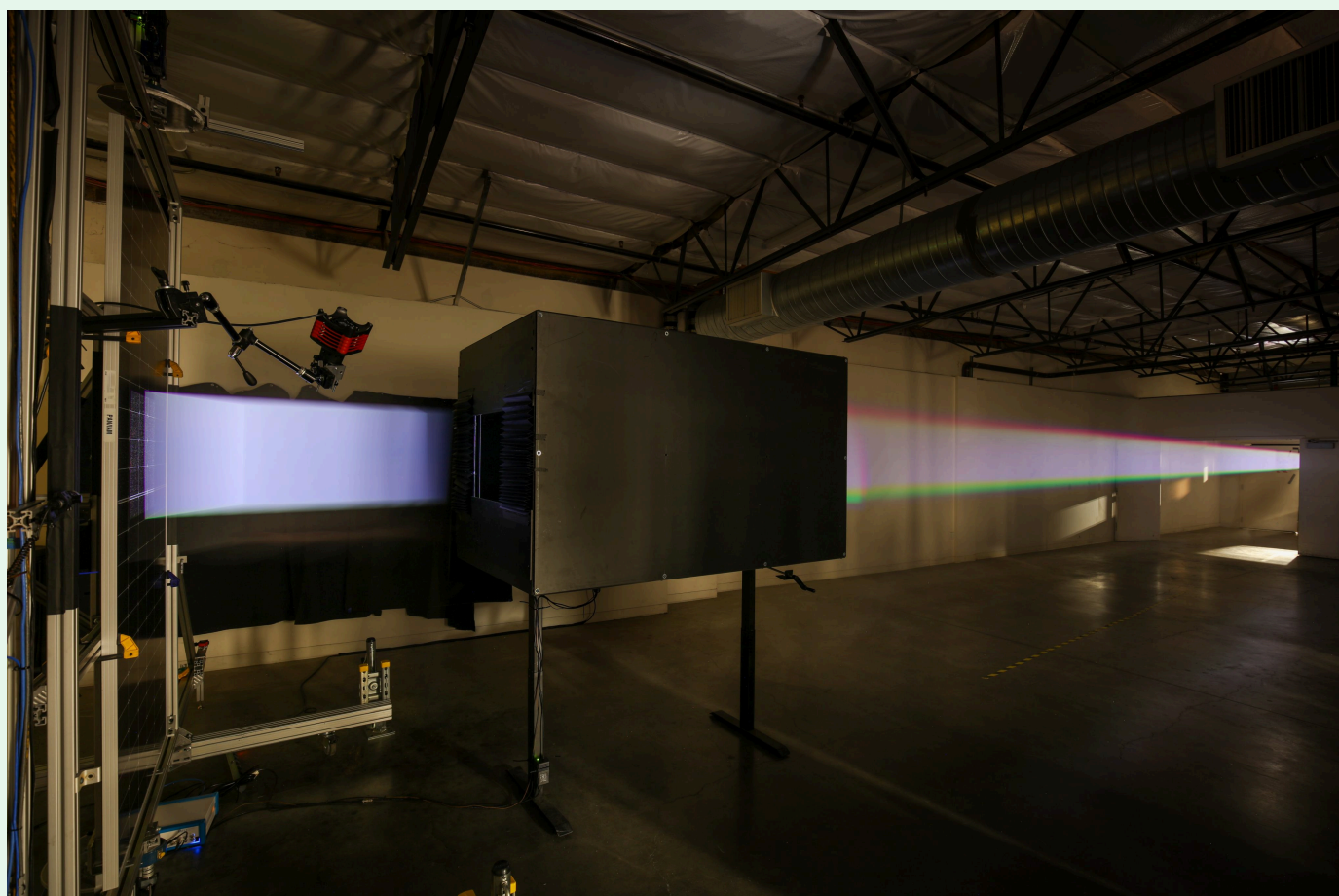
Incidence Angle *Modifier*

Incidence Angle Modifier (IAM) coefficients evaluate the response of a PV module to light coming from various angles. Kiwa PVEL has improved upon the IEC 61853-2:2016 test method to capture IAM profiles for both glass//backsheet and glass//glass modules. This unique indoor IAM testing method has demonstrated world-leading results for precision and repeatability.

IAM *Key Takeaways*

- Measurements over the past year using Kiwa PVEL's method continued to show that the IAM values for commercial modules are relatively aligned. This may contradict manufacturer-provided IAM curves.
- Kiwa PVEL can accurately measure differences in IAM performance between BOMs. The highest performer's modelled energy yield was 0.57% higher than the lowest performer for a simulated single-axis tracker site in Las Vegas, USA.
- While the sample size was lower for HJT, Kiwa PVEL's IAM measurements indicate that HJT modules on average have a lower IAM than TOPCon and PERC modules. This is likely due to the blue light absorption in the amorphous silicon for HJT cells.
- Some manufacturers/BOMs use light redirecting films (LRF) between the cells to direct reflected light toward the cells. While LRFs improve power output (when measured under normal incidence), they cause a slight reduction in IAM performance.

Go to scorecard.pvel.com/IAM to see more.



Backsheet Durability Sequence

The PQP's Backsheet Durability Sequence (BDS) goes well beyond IEC/UL certification requirements to effectively evaluate backsheet reliability, focusing on risks like yellowing and cracking due to polymer degradation. This test uses UV light, high temperature and humidity, and temperature cycling to simulate conditions that can lead to material degradation in the field.

BDS Key Takeaways

- Kiwa PVEL has still not recorded catastrophic failures during BDS testing. This testing covers a range of outer layer materials including CPC, PVF, PVDF and PET films. The backsheets were transparent, white and black.
- Bifacial modules with transparent backsheets comprise more than 60% of the test sample population in Kiwa PVEL's BDS testing. Results show that transparent backsheets suffered from more yellowing compared to white backsheets.
- Many new module backsheets have been deployed in the field over the last few years, showing no early signs of degradation. It is possible that some of these unproven backsheets may reveal potential issues over the long term.

Go to scorecard.pvel.com/BDS to see more.



PQP Failures

The PQP failure rate continued to increase over the past year, with the number of manufacturers and BOMs experiencing one or more failures now at 87% and 61%, respectively. Module breakage during MSS and HSS testing continued to be the top failure mode, but a sharp increase in delamination defects made it a close second in failure occurrences.

PQP Failures *Key Takeaways*

- 29% of BOMs undergoing MSS experienced at least one module breaking. 23% of BOMs undergoing HSS experienced a breakage failure during HSS testing. Improved designs, materials and processes are necessary to address the multiple potential causes for module breakage.
- The percentage of manufacturers experiencing delamination failures tripled over the previous year. A third of these defects came after DH testing, but delamination failures were also observed during initial characterizations and after other tests. Better encapsulant and/or lamination processes are needed to solve this issue.
- Junction box (JB) related failures decreased over the past year but still remain a significant source of PQP failures. These defects can be avoided with better bypass diodes, improved JB sealing and better JB designs.
- 26% of manufacturers had at least one power loss failure. 40% of these failures occurred after PID. Power loss failures were also recorded following TC, DH, UVID, LID and after a failed PQP sample production factory witness.

Go to scorecard.pvel.com/failures to see more.



Historical Scorecard

The table below shows the history of top performance for all manufacturers featured in the 2026 Scorecard. Go to scorecard.pvel.com/top-performers to see the list of Top Performer model numbers.

Manufacturers are listed by the number of years they have been designated a Top Performer, in alphabetical order.

Manufacturer	2026	2025	2024	2023	2022	2021	2020	2019	2018	2017	2016	2014
Jinko	■	■	■	■	■	■	■	■	■	■	■	■
Trina Solar	■	■	■	■	■	■	■	■	■	■	■	■
JA Solar	■	■	■	■	■	■	■	■	■		■	■
Qcells	■	■	■	■	■	■	■	■	■	■	■	
Astronergy	■	■	■	■	■	■	■		■	■		■
Adani Solar	■	■	■	■	■	■	■	■	■			
LONGi	■	■	■		■	■	■	■	■	■		
Phono Solar	■	■	■	■	■	■		■	■		■	
Vikram Solar	■	■	■	■	■	■	■	■		■		
GCL	■	■	■			■	■	■	■	■		
HT-SAAE	■	■	■	■	■	■	■		■			
Yingli Solar	■	■	■	■					■	■	■	■
ZNShine Solar	■	■	■	■	■		■	■			■	
DMEGC Solar	■	■	■	■	■	■						
EliTe Solar	■	■	■	■	■	■			■		■	
VSUN	■	■	■	■	■	■						
Canadian Solar	■	■	■	■			■					
Jolywood	■	■	■	■		■						
SEG Solar	■	■	■	■	■							
Waaree	■	■	■	■	■							
Aiko Solar	■	■	■	■								
Emmvee	■	■	■	■								
NE Solar	■	■	■									
ReNew	■	■	■									
Tata Power Solar	■	■	■									
Thornova	■	■	■									
Tongwei	■	■	■									
Goldi Solar	■		■									
Rayzon Solar	■	■										
RenewSys	■	■										
Atelier Solar	■											
Avaada Electro	■											
Bila Solar	■											
ES Foundry	■											
Fellow Energy	■											
Gautam Solar	■											
Grew Solar	■											
Hounen	■											
Huayao PV	■											
Illuminate USA	■											
Solex	■											
TCL Solar	■											
Toyo Solar	■											

Top Performers *Per Test*

The table below shows for which tests each manufacturer achieved Top Performer status with one or more models. In some cases, test results for some test categories were not available at the time of Scorecard publication.

Manufacturers are listed by the number of tests, followed by the number of years they have been designated a Top Performer, in alphabetical order. Go to scorecard.pvel.com/top-performers to see the list of Top Performer model numbers.

Manufacturer	TC	DH	MSS	HSS	PID	UVID	LID + LETID	PAN
Adani Solar	■	■	■	■	■	■	■	■
Jinko	■	■	■	■	■		■	■
LONGi	■	■	■	■	■	■	■	
Phono Solar	■	■	■	■	■		■	■
HT-SAAE	■	■	■	■	■	■	■	
ZNShine Solar		■	■	■	■	■	■	■
EliTe Solar	■	■	■		■	■	■	■
Canadian Solar	■		■	■	■	■	■	■
Aiko Solar	■	■	■	■	■	■	■	
ReNew	■	■	■	■	■	■	■	
Thornova	■	■	■	■	■	■	■	
Tongwei	■	■	■		■	■	■	■
RenewSys		■	■	■	■	■	■	■
Fellow Energy	■	■	■	■	■	■	■	
Illuminate USA	■	■	■	■	■	■	■	
Trina Solar	■		■	■	■		■	■
Qcells		■	■	■		■	■	■
Yingli Solar	■		■	■	■	■	■	
VSUN	■		■	■	■		■	■
SEG Solar	■	■	■	■	■		■	
Waaree	■	■	■		■		■	■
EMMVEE	■	■	■	■	■		■	
NE Solar		■	■	■	■	■	■	
Goldi Solar	■	■		■	■		■	■
Avaada Electro	■	■		■	■	■	■	
Grew Solar	■	■	■	■	■		■	
Toyo Solar	■		■	■	■		■	■
JA Solar	■	■	■		■		■	
Astronergy		■	■	■	■		■	
GCL	■	■	■		■		■	
DMEGC Solar	■	■	■		■			■
Bila Solar	■	■	■		■		■	
ES Foundry	■	■	■		■		■	
Hounen			■	■	■		■	■
Solex	■	■	■	■	■			
TCL Solar	■	■	■			■	■	
Vikram Solar	■				■		■	■
Rayzon Solar	■	■	■				■	
Atelier Solar		■	■	■	■			
Huayao PV		■	■	■	■			
Tata Power Solar				■		■		■
Gautam Solar	■	■			■			
Jolywood			■	■				

About *Kiwa PVEL*

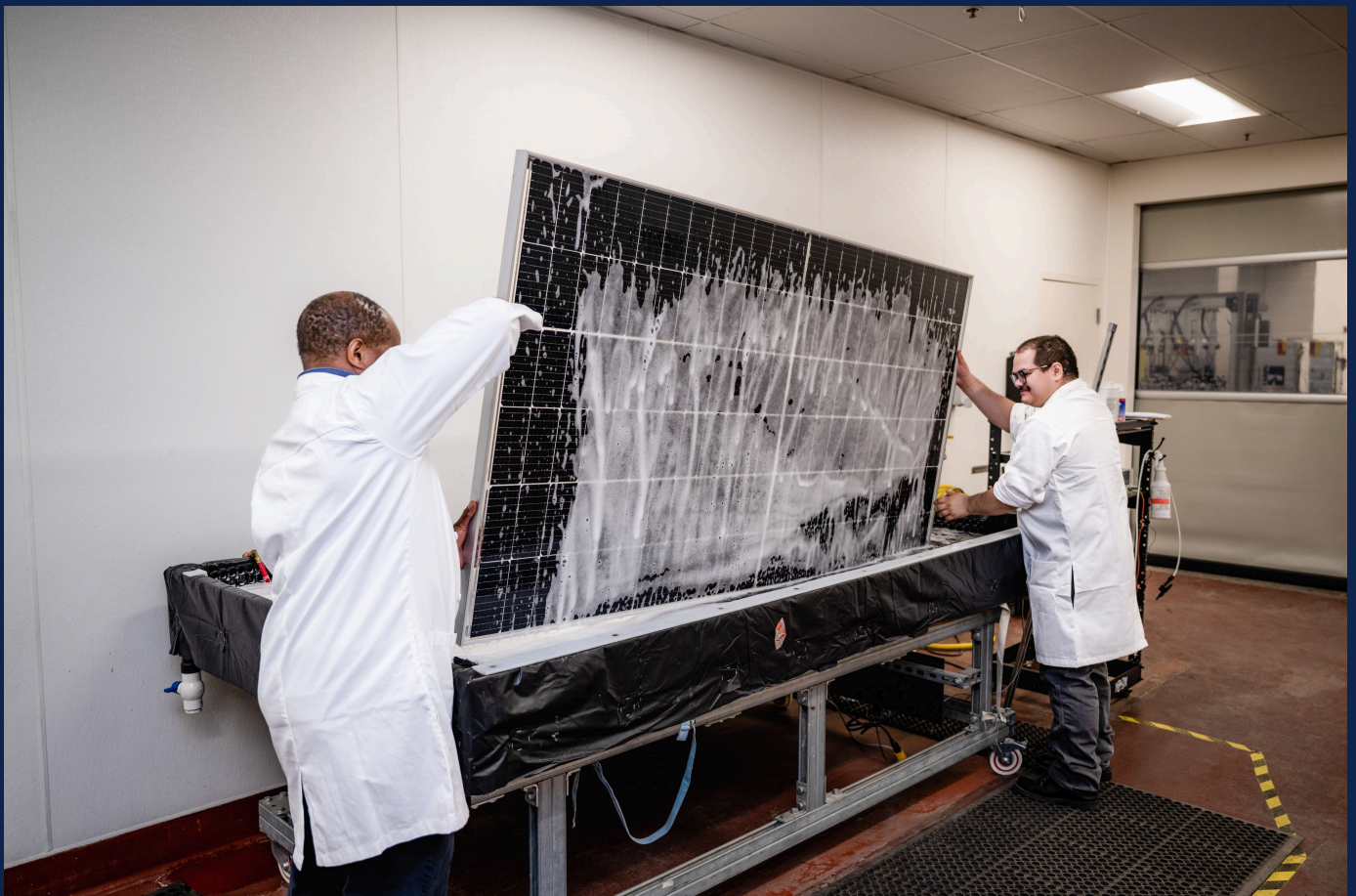
Kiwa PVEL is the leading reliability and performance testing lab for downstream solar project developers, financiers and asset owners around the world. For over a decade, Kiwa PVEL's Product Qualification Program (PQP) has been globally recognized for replacing assumptions about PV module performance with quantifiable metrics. Related data and consulting services offered by Kiwa PVEL provide vital procurement intelligence to a network of downstream solar buyers.

Visit kiwa.com/pvel for more.

About *Kiwa Solar*

The Kiwa Group offers a comprehensive portfolio of quality assurance, testing, inspection and certification services for the solar industry. This includes component certification, qualification and bankability testing, technical due diligence, factory audits and inspections, batch testing and field services at operating sites and those under construction. We support investors, developers, EPC contractors and asset managers, while also helping manufacturers demonstrate compliance with the requirements of numerous markets.

Visit kiwa.com/solar for more.



Go Online for More!

Go to scorecard.pvel.com to access:

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