2024 PV Module Reliability Scorecard

TOP PERFORMER 2024
kiwa PVEL
PV MODULE RELIABILITY SCORECARD

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PVEL

Executive Summary

Welcome to the 10th Edition of Kiwa PVEL's PV Module Reliability Scorecard, celebrating a decade of technological progress, industry insight and PV module top performance.

Welcome to Kiwa PVEL's

2024 Scorecard Executive Summary

For this 10th Scorecard, Kiwa PVEL is honored to present even more Top Performer manufacturers. New for this year, we have given special distinction to manufacturers that are Top Performers in multiple tests. We have also introduced a Top Performer category for hail testing, set a higher bar for Top Performers in LID+LETID and PAN, and added pages on IAM and UVID at scorecard.pvel.com.

The Scorecard equips buyers with essential information, but module procurement remains nuanced. We caution that the Scorecard is not a shopping list. Accessing the full PQP test reports and specifying top performing bills of materials are essential steps within Kiwa Solar's procurement best practices. Beyond the Scorecard, Kiwa PVEL's Premium Partner Program provides more granular data and quarterly updates, helping multiple companies procure better modules. Find out more at kiwa.com/pvel/ppp.

Thank you for turning to Kiwa PVEL for your industry insights and enjoy the 2024 Scorecard!

Executive Summary Contents

This Executive Summary offers readers a brief overview of Kiwa PVEL's Product Qualification Program (PQP) methodology, tests and Scorecard scoring. Key takeaways from each of the Top Performer PQP tests are also included, which highlight the latest test findings. The Historical Scorecard is also presented, showing all of the 2024 Top Performer manufacturers and their history of Scorecard appearances, as well as a new page 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 tests in the Executive Summary, plus UVID, IAM, BDS and PQP failures.
- Direct links to test specific pages on kiwa.com for field case studies, test procedures and more.

Table of Contents

Methodology

Kiwa PVEL's approach to testing and benchmarking PV module reliability has been our key focus for more than a decade. The PQP enables data-driven solar procurement and investments for developers, financiers, and asset owners.

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 Scorecard, manufacturers must have:

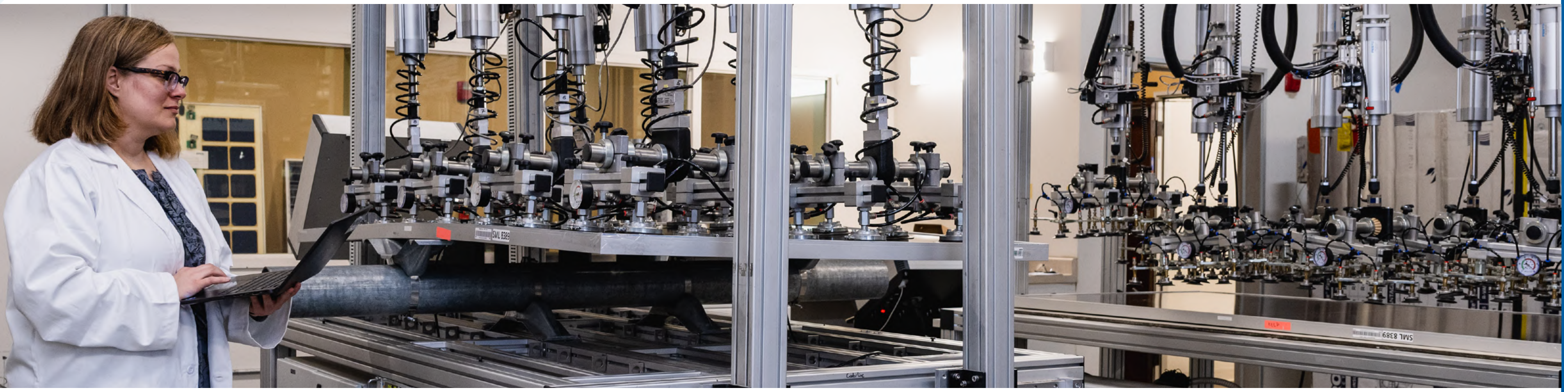
- Completed the PQP sample production factory witness after October 1, 2022.
- Submitted at least two factory-witnessed PV module samples to all PQP reliability tests, as per Kiwa PVEL's BOM test requirements.

How BOMs are Scored

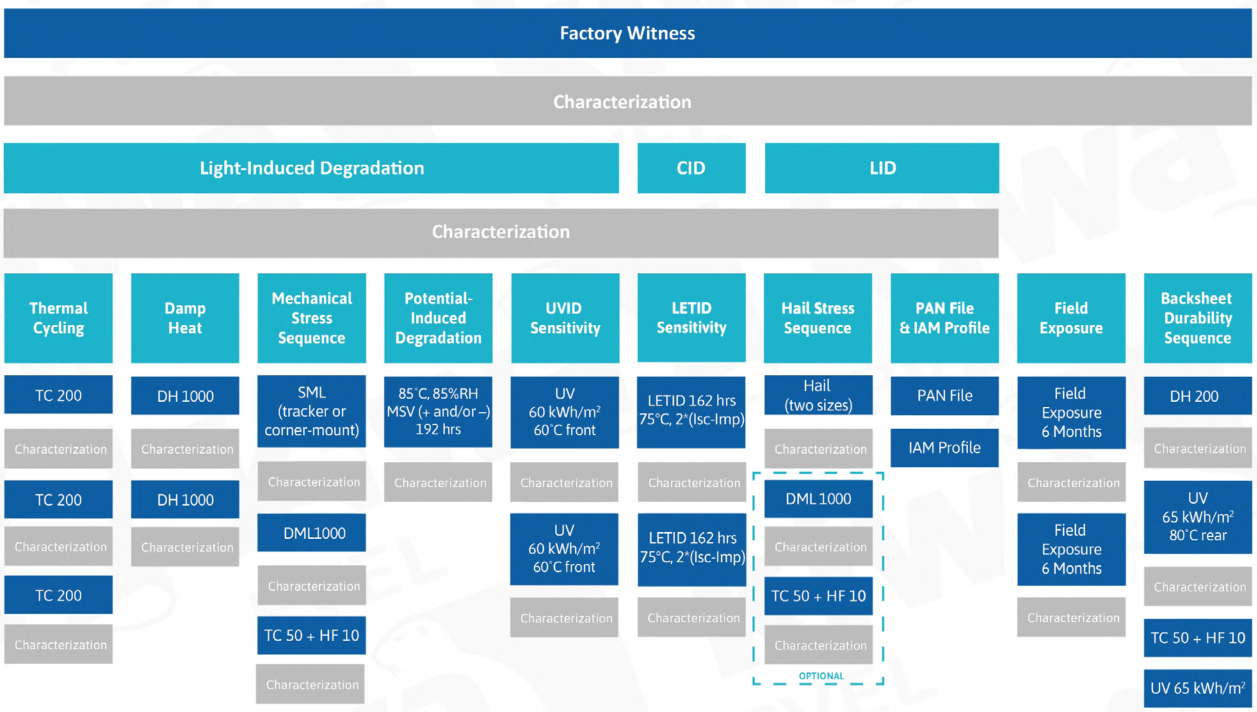
The 2024 Scorecard lists Top Performers for seven PQP test categories. Top Performers are determined by averaging that specific test's results for every BOM tested by Kiwa PVEL that is sold under the same model type.

- Top Performers for TC, DH, MSS and PID must have < 2% power degradation.
- Top Performers for HSS must not have experienced glass breakage during hail testing using 40 mm hail or larger.
- 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.

To be listed as a Top Performer, the modules must not have experienced a wet leakage failure, a 'major' defect during visual inspection or a diode failure during that particular test.



Kiwa PVEL's PV Module PQP



Factory Witness

All Bills of Materials submitted for testing are witnessed in production from opening of raw materials packages through every step of the production process to final packaging with tamper-proof tape.

Testing Abbreviations

TC: Thermal cycling
DH: Damp heat
UV: Ultraviolet
HF: Humidity freeze
LETID: Light and elevated temperature-induced degradation
IAM: Incidence angle modifier
PAN File: PVSyst .pan file
MSV: Maximum system voltage
FE: Field exposure
UVID: Ultraviolet induced degradation
SML: Static mechanical load
DML: Dynamic mechanical load
CID: Current induced degradation

Characterizations

IV: Flash test at STC
EL: EL image at Isc
LIC: Flash test at 200W/m²
LCEL: EL image at 1/10*Isc
VWL: Visual inspection and wet leakage
Diode: Diode test
Connector: Connector resistance measurement
Color: Backsheet color measurement
Capacity: Capacity testing

Note: Not all measurements are taken at each step

2024 Scorecard - Key Takeaways

- The 2024 Scorecard features more manufacturers than ever before, including 20 manufacturers who are first time Top Performers.
- Less than 6% of the Top Performer models achieved this status in all reliability tests (TC, DH, MSS, HSS, PID and LID+LETID), and only four models were Top Performers in those plus PAN.
- The MSS and LID+LETID results continued to be strong and PAN results improved, but there was an increase in lower performing outliers for TC and DH, and in the median PID power loss.
- 66% of module manufacturers experienced at least one test failure, the highest percentage ever reported. The BOM-level failure rate also increased.

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 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.

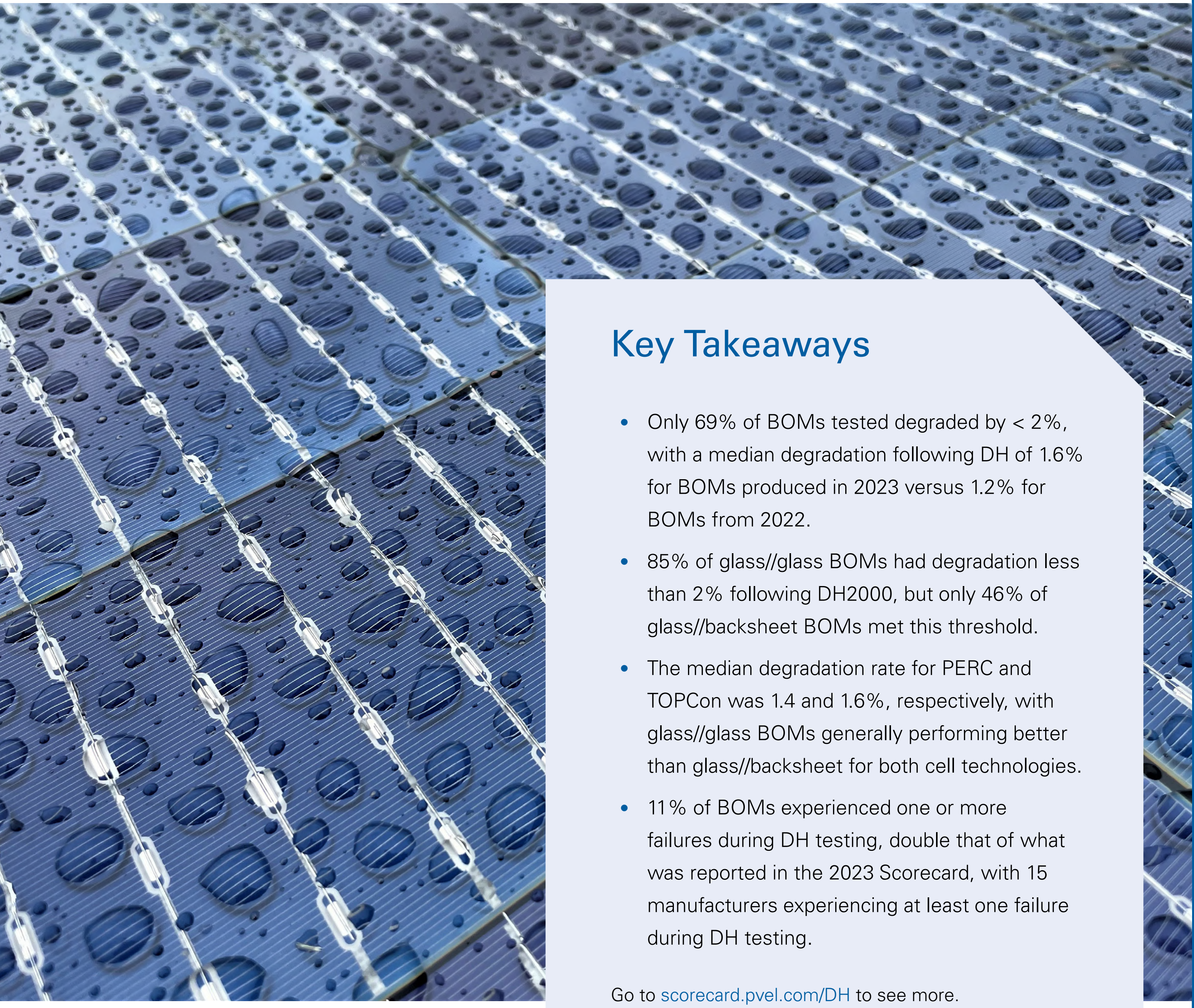
Key Takeaways

- 84% of BOMs tested degraded by < 2%, with a median degradation of 0.8% following TC. But the number of outliers and failures has increased.
- The median power loss was 0.6% for glass//glass versus 1.7% for glass//backsheet. 95% of glass//glass BOMs had < 2% degradation following TC600 versus only 50% of glass//backsheet BOMs.
- The median degradation rate for PERC and TOPCon was 0.6 and 0.7%, respectively, but the number of power degradation failures was higher for TOPCon modules. HJT BOMs showed improved TC results compared to previous years.
- 11% of BOMs experienced one or more failures during TC testing, and 11 manufacturers experienced at least one failure during TC testing, including some major junction box issues and power loss.

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.



Key Takeaways

- Only 69% of BOMs tested degraded by < 2%, with a median degradation following DH of 1.6% for BOMs produced in 2023 versus 1.2% for BOMs from 2022.
- 85% of glass//glass BOMs had degradation less than 2% following DH2000, but only 46% of glass//backsheet BOMs met this threshold.
- The median degradation rate for PERC and TOPCon was 1.4 and 1.6%, respectively, with glass//glass BOMs generally performing better than glass//backsheet for both cell technologies.
- 11% of BOMs experienced one or more failures during DH testing, double that of what was reported in the 2023 Scorecard, with 15 manufacturers experiencing at least one failure during DH testing.

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 through load testing followed by climate chamber testing and is crucial for sites facing extreme weather such as heavy snow and high winds.

Key Takeaways

- 95% of BOMs completing MSS had < 2% power loss. However, power loss from this test is expected to increase in the coming year with the test changing from traditional fixed-tilt mounting to more aggressive tracker or corner mounting.
- While glass//glass modules have repeatedly been shown to protect the cells, Kiwa PVEL has received multiple reports of broken glass//glass modules in the field from locations around the globe.
- Some glass//backsheet BOMs tested with 400 mm tracker mounting (at ±1800 Pa) showed the worst MSS results. Extreme deflection can push the backsheet and cells against the torque tube, leading to excessive cell cracking.
- 7% of BOMs experienced one or more failures during MSS testing. Nine manufacturers experienced at least one failure during MSS testing, including glass breakage, frame breakage and delamination.

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.

Key Takeaways

- 89% of 2.0 mm heat strengthened glass//glass modules experienced glass breakage due to 50 mm hail compared to 40% for 3.2 mm fully tempered glass//backsheet modules.
- There was no hail-related power degradation > 3% due to glass//glass modules protecting the cells from cracking within the neutral plane, and the use of half-cut, multi-bus bar (MBB) cells.
- Kiwa PVEL's hail testing has been almost exclusively for 2.0 mm glass//glass and 3.2 mm glass//backsheet, but three tested BOMs of 2.5 mm glass//glass showed no glass breakage with 50 mm hail.
- Glass breakage typically is not considered a Scorecard "failure," but some manufacturers required multiple retests of the same hail diameter before achieving the desired hail test performance, and three manufacturers had modules where the junction box lid fell off due to hail impacts.

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.

Key Takeaways

- Only 58% of BOMs tested degraded by < 2%, and the median degradation following PID increased to 1.8% for BOMs produced in 2023.
- Results were aligned across module types and cell technologies. The median degradation for glass//glass, glass//backsheet, PERC and TOPCon all ranged from 1.6 to 2.0%.
- The choice of encapsulant supplier/type can impact PID results. One manufacturer submitted three TOPCon glass//glass BOMs using the identical cell model, but with different encapsulant suppliers. The PID power loss for the three BOMs was 1.12%, 2.59% and 3.32%.
- 11 manufacturers experienced a "failure" during PID testing. While a few of these were undoubtedly manufacturing defects (for example, a junction box fell off a PID module), most were due to power degradation caused by PID-polarity, which is often reversable with UV exposure.

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. LETID most predominantly affected early generation PERC cells and is more severe in hotter climates.

Key Takeaways

- 96% of BOMs tested had < 1% power loss, with a 0.3% median degradation when combining the average LID value and the average LETID value for each BOM produced in 2023.
- The median power loss for LID+LETID was 0.3% for gallium-doped p-type PERC and 0.2% for n-type cell technologies (TOPCon, HJT and xBC), showing that these technologies are generally not susceptible to these degradation modes.
- In November 2023, Kiwa PVEL launched the latest PQP which includes current-induced degradation (CID) preconditioning on the LETID samples rather than LID. Across the limited number of BOMs tested thus far, the CID and LID test results are not yet statistically correlated.
- A surprising 26% of manufacturers experienced at least one pre-stress testing failure, including missing junction box lids, peeling nameplate labels, wet leakage testing failures, delamination and diode failures.

Go to scorecard.pvel.com/LID-LETID 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.

Key Takeaways

- With an increase in the number of TOPCon modules included in the PAN dataset for the 2024 Scorecard, the Top Performer energy yield threshold for Kiwa PVEL's modelled site in Las Vegas increased by 0.95% compared to what was reported last year.
- The limited number of HJT BOMs in the 2024 Scorecard dataset showed an average Pmp temperature coefficient of -0.26%/°C compared to -0.30%/°C for TOPCon and -0.32%/°C for PERC.
- The average HJT bifaciality was 86.7% compared to 75.4% for TOPCon and 69.3% for PERC. This leads to significantly higher modelled energy yield for HJT, followed by TOPCon, when compared to PERC modules.
- PERC's low light performance (as measured via the relative efficiency deviation at 200 W/m^2 compared to 1000 W/m^2) marginally improved over the 2023 Scorecard, but TOPCon's low light performance decreased.

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

Historical Scorecard

TOP PERFORMER 2024 kiwa PVEL PV MODULE RELIABILITY SCORECARD

The table below shows the history of top performance for all manufacturers featured in the 2024 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	2024	2023	2022	2021	2020	2019	2018	2017	2016	2014
Jinko	•	•	•	•	•	•	•	•	•	•
Trina Solar	•	•	•	•	•	•	•	•	•	•
JA Solar	•	•	•	•	•	•	•		•	•
Qcells	•	•	•	•	•	•	•	•	•	
Astronergy	•	•	•	•	•		•	•		•
Adani Solar	•	•	•	•	•	•	•			
LONGi	•		•	•	•	•	•	•		
Maxeon Solar	•	•	•	•	•		•	•		
Phono Solar	•	•	•	•		•	•		•	
Vikram	•	•	•	•	•	•		•		
Boviet Solar	•	•	•	•	•	•				
GCL	•			•	•	•	•	•		
HT-SAAE	•	•	•	•	•		•			
Silfab Solar	•	•		•	•	•		•		
Suntech	•		•		•	•	•			•
Yingli	•	•					•	•	•	•
ZNShine Solar	•	•	•		•	•			•	
DMEGC	•	•	•	•						
EliTe Solar	•	•	•	•						
HD Hyundai	•	•		•				•		
Heliene	•	•	•		•					
Risen Energy	•	•	•	•						
VSUN	•	•	•	•						
Canadian Solar	•	•			•					
Jolywood	•	•		•						
SEG Solar	•	•	•							
Waaree	•	•	•							
Aiko	•	•								
EGing PV	•	•								
Emmvee	•	•								
Huasun	•	•								
Premier Energies	•	•								
SolarSpace	•	•								
DAS Solar	•									
Dehui	•									
Golden Solar	•									
Goldi	•									
Hanersun Energy	•									
Imperial Star	•									
Jakson	•									
Jinergy	•									
Leapton Solar	•									
Meyer Burger	•									
Mission Solar Energy	•									
NE Solar	•									
PT.IDN SOLAR TECH	•									
Qn-Solar	•									
ReNew	•									
Runergy	•									
Saatvik	•									
Tata Power Solar	•									
Thornova	•									
Tongwei 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	LID+LETID	PAN
Trina Solar	•	•	•	•	•	•	•
Boviet Solar	•	•	•	•	•	•	•
HT-SAAE	•	•	•	•	•	•	•
Risen Energy	•	•	•	•	•	•	•
VSUN	•	•	•	•	•	•	•
SEG Solar	•	•	•	•	•	•	•
Emmvee	•	•	•	•	•	•	•
Meyer Burger	•	•	•	•	•	•	•
NE Solar	•	•	•	•	•	•	•
JA Solar	•	•	•	•	•	•	
Astronergy	•	•	•	•		•	•
LONGi		•	•	•	•	•	•
Maxeon	•	•	•	•	•	•	
Canadian Solar	•	•	•	•	•	•	
Jolywood	•	•	•		•	•	•
Waaree	•	•	•		•	•	•
Aiko Solar	•	•	•	•	•	•	
EGing PV	•	•	•	•		•	•
Premier Energies	•	•	•	•	•	•	
Imperial Star	•	•	•	•	•	•	
Tongwei	•	•	•	•	•		•
Jinko	•	•	•	•	•		
Vikram Solar	•	•	•		•	•	
Silfab Solar	•	•	•	•		•	
Suntech	•	•	•		•	•	
Yingli Solar	•	•	•			•	•
DMEGC Solar	•	•	•		•	•	
EliTe Solar	•	•	•			•	•
HD Hyundai	•		•	•	•	•	
SolarSpace	•	•	•		•	•	
DAS Solar	•	•	•			•	•
Qn-SOLAR	•	•	•		•	•	
ReNew		•	•	•	•	•	
Runergy	•	•	•			•	•
Thornova	•	•	•			•	•
Adani Solar			•	•	•		•
GCL	•		•		•	•	
ZNShine Solar			•		•	•	•
Huasun	•		•			•	•
Goldi Solar	•	•			•	•	
Jakson			•	•	•	•	
Jinergy		•	•		•	•	
Leapton	•	•		•		•	
Tata Power Solar	•			•	•	•	
Qcells	•	•	•				
Phono Solar					•	•	•
Heliene				•	•	•	
Golden Solar	•				•	•	
Hanersun			•	•		•	
PT.IDN SOLAR TECH	•	•	•				
Dehui			•			•	
Mission Solar				•			
Saatvik				•			

About Us

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 the 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.

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