MAKE DATA MATTER.

SEVENTH EDITION: PDF FORMAT

# 2021 PV Module Reliability Scorecard

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PV EVOLUTION LABS

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## About PV Evolution Labs

PV Evolution Labs (PVEL) is the leading reliability and performance testing lab for downstream solar project developers, financiers, and asset owners and operators around the world and a member of the Kiwa Group. With over ten years of experience and accumulated data, PVEL conducts testing that demonstrates solar technology bankability. Its trusted, independent reports replace assumptions about solar equipment performance with data-driven, quantifiable metrics that enable efficient solar project development and financing.

The PVEL network connects all major PV and storage manufacturers with 400+ global Downstream Partners representing 30+ gigawatts of annual buying power. PVEL's mission is to support the worldwide PV downstream buyer community by generating data that accelerates adoption of solar technology. Learn more online at pvel.com.

member of group
kiwa

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# Introduction

**There is no shortage of data today. But in a world of fake news, the challenge is finding the right data – the data that matters.**

PVEL's 2021 PV Module Reliability Scorecard recognizes manufacturers with exemplary test results in our Product Qualification Program (PQP). But that is not the only data that matters for reliable solar power. This Scorecard extends beyond prior editions with more field data that connects lab testing to real-world project applications.

Our findings reflect the resilience of the solar industry. Despite a global pandemic, demand for solar power is increasing. Manufacturers are rising to the challenge. Exawatt, a market intelligence provider and PVEL partner, predicts that over 100 GW of new module production capacity will come online by the end of 2021.

Manufacturers are also innovating to overcome supply constraints for key components such as glass, silver, even polysilicon. Technical advances are driving power classes past 500W in commercial PV modules. When buyers purchase brand-new products, their modules will almost certainly be produced in brand-new factories. Deploying these unproven bills of materials (BOMs) in the field can have profound financial implications and safety consequences.

Product quality should not be sacrificed for growth when vital infrastructure is at stake, but it does occur. Twenty-six percent of the BOMs tested for this year's Scorecard had at least one failure – an absolute increase of six percent over last year. One in three manufacturers experienced a junction box failure, and the majority of failures occurred before testing even began. Troubling junction box issues were first noted by PVEL in 2018.

Fortunately, PV module buyers are not forced to choose between scale and quality. From the lab to the field, independent testing provides data that developers, investors and asset owners can leverage as safeguards against project underperformance.

The 7th edition of PVEL's PV Module Reliability Scorecard is a compilation of trusted data that informs the development of reliable, financeable solar projects. Our goal is to drive deployment of solar assets that will operate as expected, even in an uncertain world.

**JENYA MEYDBRAY**
CEO
PV EVOLUTION LABS (PVEL)

# Solar Quality by the Numbers

## Unprecedented Growth Brings Unprecedented Challenges

100 million solar cells are soldered every day to meet PV module demand. PVEL has observed degradation rates **>15%** in testing.

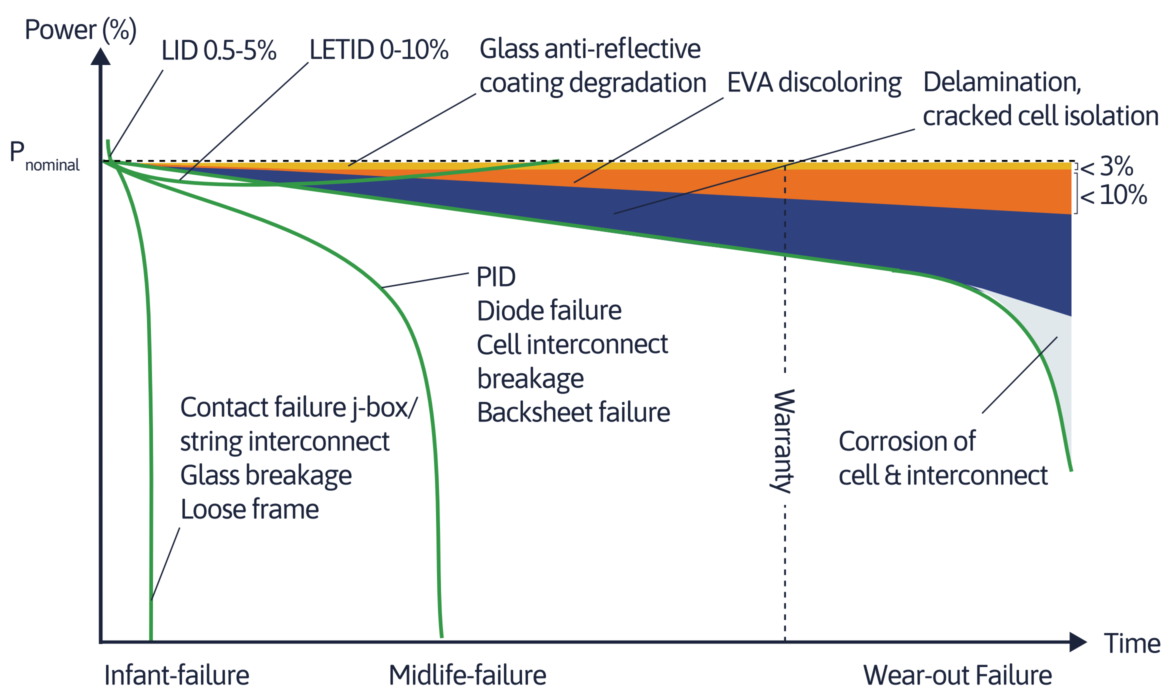
## More Growth Coming

To address climate change, we will need to reach at least **1,000,000,000 cells** soldered per day.

## Quality cannot be sacrificed for scale.

### PV Module Failures

Reliable PV module performance depends on stringent manufacturing process controls and well-made components. When manufacturers overlook quality assurance and quality control steps or use substandard materials, premature failure in modules is likely to occur. An overview of common failure modes is shown below.



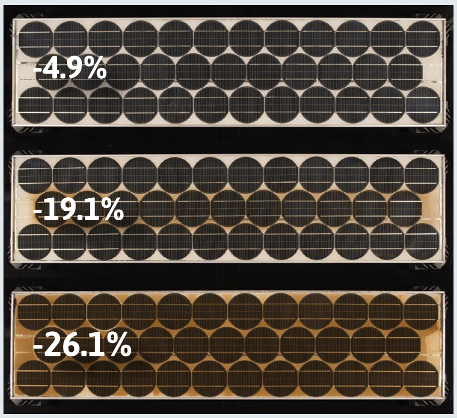

*Source: IEA PVPS 2014; LETID and backsheet failure added by PVEL, 2019*

# Reliability in the Field

## 35 Years of Field Exposure Proves that BOM Matters

A recent study of Europe's first grid-connected solar project, the TISO-10-kW plant in Switzerland, demonstrates the profound impact of material selection on long-term field performance. **The use of quality materials in some modules resulted in >20% higher power output after 35 years of field operation.**

Researchers determined that the use of different encapsulant formulations was the primary cause of degradation rate variability. While modules with one type of encapsulant degraded just 4.9% on average after 35 years, modules with two other encapsulant formulations exhibited much higher mean degradation rates of 19.1% and 26.1%.




***PV modules with different encapsulant formulations were exposed to the exact same field conditions for thirty-five years. One type of encapsulant remains transparent with minimal signs of aging, but one is aging severely, and one is aging moderately.***

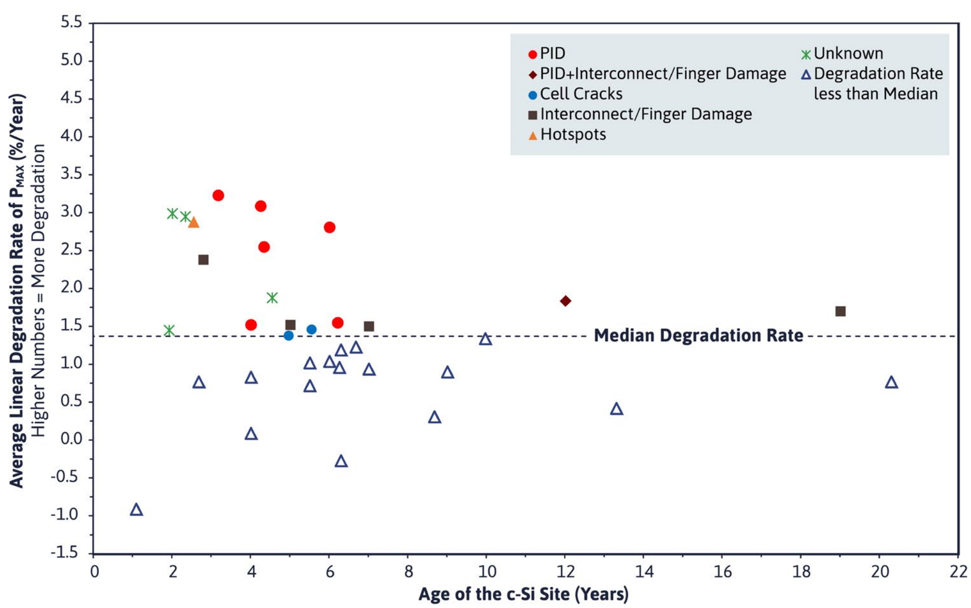
*Sources: Virtuani A, Caccivio M, Annigoni E, Friesen G, Chianese D, Ballif C, Sample T, 35 years of photovoltaics: Analysis of the TISO-10-kW solar plant, lessons learnt in safety and performance — Part 1, Prog Photovolt Res Appl. 2019;27:328–339, DOI: 10.1002/pip.3104 Annigoni, E, Virtuani, A, Caccivio, M, Friesen, G, Chianese, D, Ballif, C. 35 years of photovoltaics: Analysis of the TISO-10-kW solar plant, lessons learnt in safety and performance—Part 2. Prog Photovolt Res Appl. 2019; 27: 760– 778. https://doi.org/10.1002/pip.3146*

## Higher Degradation Rates in New Modules

In-depth studies of 36 solar projects in India show that modules with less than five years of field operation have higher average degradation rates than older modules, especially in hot climates. Across all sites, an average LID-discounted annual degradation rate of 1.47% was observed, which is higher than the 0.7% specified in most manufacturers' linear performance warranties. Degradation was typically much higher in hot areas than in colder, mountainous regions where rates of 0.7% were observed.

***According to the researchers, the use of substandard material components and insufficient quality controls as the industry expands must be considered as potential causes when newer solar projects underperform.***

The findings may undermine the financial viability of 40-year modeled lifetimes for modern solar power plants that assume aggressive annual degradation rates, particularly if rigorous due diligence that includes BOM specification is not conducted.

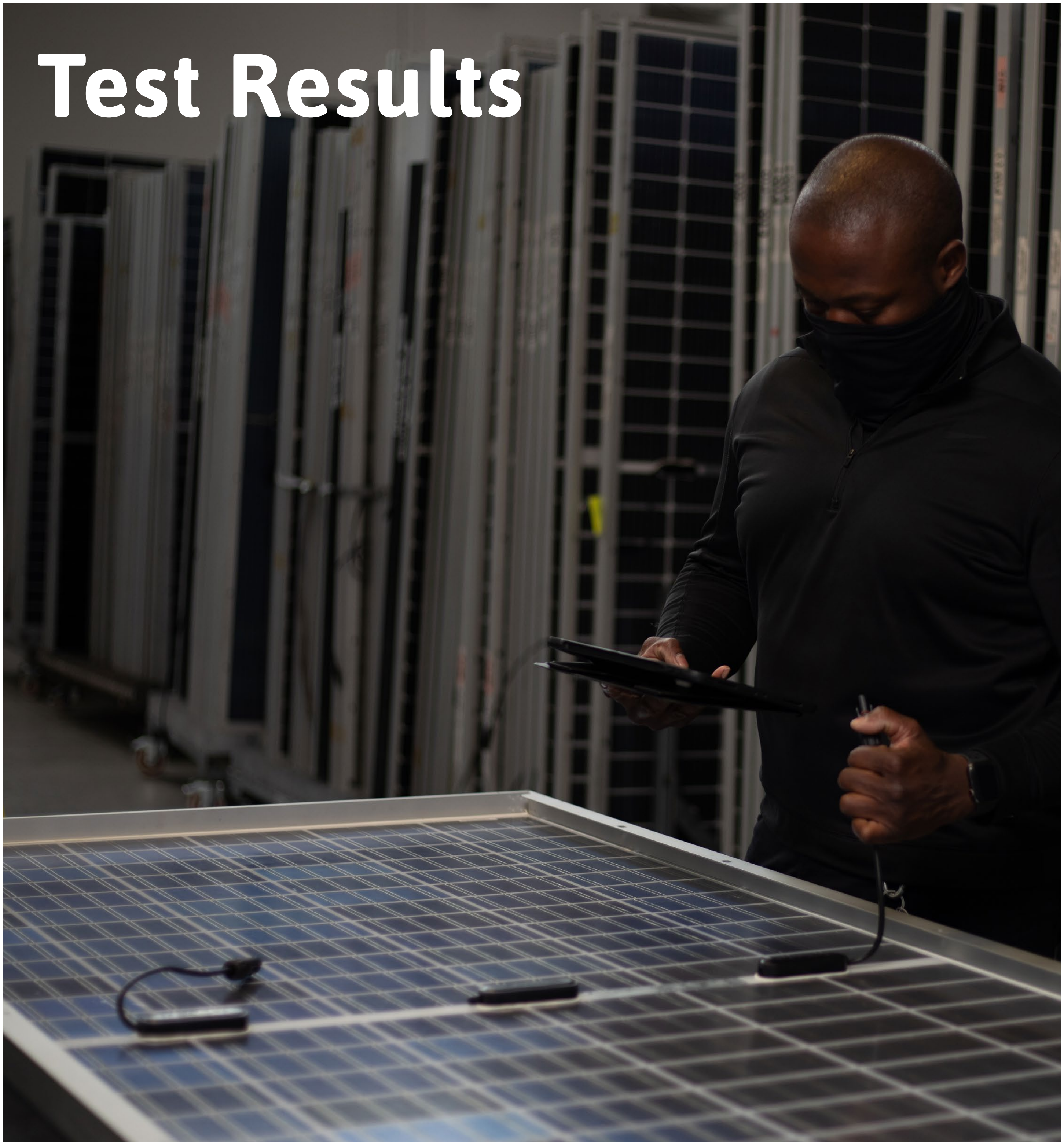



*Sources: Yogeswara Rao Golive, Sachin Zachariah, Rajiv Dubey, Shashwata Chattopadhyay, Sonali Bhaduri, Hemant K. Singh, Anil Kottantharayil, Birinchi Bora, Sanjay Kumar, Tripathi A.K., Vasi Juzer, Narendra Shiradkar, "Analysis of Field Degradation Rates Observed in the All India Survey of PV Module Reliability 2018", IEEE Journal of Photovoltaics, Vol. 10, Issue 2, pp. 560-567, Mar. 2020. Yogeswara Rao Golive et al., "All-India Survey of Photovoltaic Module Reliability: 2018", A Report by the National Centre for Photovoltaic Research and Education (NCPRE), IIT Bombay.*

***"We find evidence in this one system that the system degrades at a rate comparable with the worst modules, implying that…systems will degrade faster than the average module rate when the modules show a spread of degradation rates. The performance appears to be limited by the worst performing module and string."***

*Source: D. C. Jordan, B. Sekulic, B. Marion and S. R. Kurtz, "Performance and Aging of a 20-Year-Old Silicon PV System," in IEEE Journal of Photovoltaics, vol. 5, no. 3, pp. 744-751, May 2015, doi: 10.1109/JPHOTOV.2015.2396360.*

# Test Results



# Methodology

**Scorecard rankings are based on results from PVEL's Product Qualification Program (PQP) for PV modules. The program, established in 2012, provides independent reliability and performance data and recognition for manufacturers who excel in testing.**

PQP starts with PVEL's factory witness, where auditors monitor production and record the bill of materials of every module submitted for testing. Following shipping, PVEL measures power output and assesses the physical condition of each module before conducting extended reliability and performance testing. The test program is detailed in the PQP diagram on page 10.

The PQP supports solar equipment buyers, investors and asset owners with a methodical test program that enables objective supplier evaluations and rigorous due diligence.

## Four Principles Guide the PQP

**Empirical data**
The PQP provides empirical metrics for revenue and energy yield modeling.

**No hand-picked samples**
Auditors witness production of all test samples and record bills of materials (BOMs).

**Standard processes**
The PQP tests all BOMs in the same way with calibrated equipment and in consistent test environments.

**Regular program updates**
Test sequence updates provide data on new technologies and manufacturing techniques.

**Developers and investors around the world now require PQP for procurement risk mitigation. Click here to join PVEL's Downstream Partner Network. Members receive free access to PQP reports.**

## Industry Perspective: PQP Benefits for Manufacturers

***"Since Boviet began PQP testing with PVEL in 2018 our sales have increased by over 100%.***

***The PVEL PQP quickly became instrumental to our long-term growth strategy: PVEL's trusted and independent product validation is now fundamental in Boviet's go to market strategy for all of our products."***

**Sienna Cen,**
**President – Boviet Solar USA**

BOVIET SOLAR USA

# Factory Witness

**PVEL auditors follow an eight-step process to inspect PV module factories and verify the BOM.**

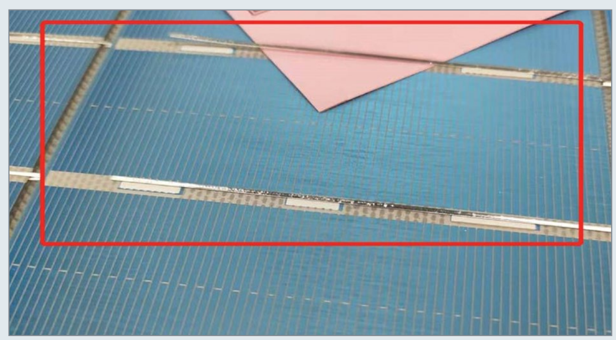
1. Conduct a high-level process audit of the factory.
2. Photograph BOM components as materials are removed from original packaging.
3. Observe and record over 100 technical details about the BOM.
4. Strictly track each BOM component through every step of production.
5. Collect backsheet, encapsulant and connector samples.
6. Document recipes for soldering and laminating.
7. Sign each module and seal pallets with tamperproof tape.
8. Ship pallets directly to PVEL for PQP testing.

**Buyers should specify approved BOMs in supply agreements to make sure they procure modules that performed well in PQP testing. Click here to ask PVEL for free, detailed BOM listings to accompany supply agreements.**

## Industry Perspective: Factory Audits

Clean Energy Associates (CEA) has completed more than 45 GW of quality assurance (QA) audits at 350 factories worldwide. PVEL recommends QA audits to buyers as a procurement best practice and includes several important QA audit protocols in PQP factory witnesses. CEA's quality control engineers regularly encounter issues such as:

- Cell ribbon misalignment
- Poor/cold soldering
- Poor pottant curing
- Inaccurate electrical test results
- Overlooked defects in EL images



*Poor soldering can be identified with a visual paper gap test. Photo courtesy of CEA.*

Poor/cold soldering is one of the most commonly observed problems. It can lead to hotspots, low module power or even module failure in the field. Poor soldering occurs on automated lines if the tabbing/stringing machine operates outside of the set specifications or the wrong settings were input. On manual production lines, the cause is operator error.

Poor soldering can be mitigated by regularly ensuring that tabbing/stringing machines are set to correct specifications and by performing quality checks such as visual inspection, EL imaging and gap tests.

**Contributed by:**
**Morgan Oats**
**Marketing Manager**
**Clean Energy Associates**

# PVEL's PV Module Product Qualification Program (PQP)

**Factory Witness**

**Intake Characterizations**

**Light Soaking for Light-Induced Degradation**

**Post-Light Soaking Characterizations**

| Thermal Cycling | Damp Heat | Backsheet Durability Sequence | Mechanical Stress Sequence | Potential-Induced Degradation | LeTID Sensitivity | PAN File & IAM Profile | Field Exposure |
|---|---|---|---|---|---|---|---|
| TC 200 | DH 1000 | DH 1000 | Static Mechanical Load | 85˚C, 85%RH MSV (+ and/or –) 96 hrs | LeTID 162 hrs (75°C, Isc-Imp) | PAN File | Field Exposure 6 Months |
| Characterization | Characterization | Characterization | Characterization | Characterization | Characterization | IAM Profile | Characterization |
| TC 200 | DH 1000 | UV 65 kWh/m² | Dynamic Mechanical Load | 85˚C, 85%RH MSV (+ and/or –) 96 hrs | LeTID 162 hrs (75°C, Isc-Imp) | | Field Exposure 6 Months |
| Characterization | Characterization | Characterization | Characterization | Characterization | Characterization | | Characterization |
| TC 200 | Stabilization 85°C, Isc, 48 hrs | TC 50 + HF 10 | TC 50 | | LeTID 162 hrs (75°C, Isc-Imp) | | |
| Characterization | Characterization | Characterization | Characterization | | Characterization | | |
| | | UV 65 kWh/m² | HF 10 | | | | |
| | | Characterization | Characterization | | | | |
| | | TC 50 + HF 10 | | | | | |
| | | Characterization | | | | | |
| | | UV 65 kWh/m² | | | | | |
| | | Characterization | | | | | |
| | | TC 50 + HF 10 | | | | | |
| | | UV 6.5 kWh/m² | | | | | |
| | | Characterization | | | | | |

**For bifacial modules, PVEL conducts additional rear side characterizations and field exposure over two albedos.**

# Results Overview

### The 2021 PV Module Reliability Scorecard shows Top Performers for six PQP test categories.

Each set of results shows Top Performers by model type in alphabetical order by manufacturer. An example of a module with high levels of degradation is provided for each reliability test, complete with electroluminescence (EL) images and flash test results.  Results also show a chart of average power degradation for each module model that includes current and historical data.

Top Performers are determined by averaging results of every BOM tested by PVEL that is sold under the same model type. While individual BOMs are not marketed to buyers, PQP reports make it possible to procure BOMs that performed well in testing.

**Not all products or model types are represented in every test. Manufacturers with top results can choose not to be listed in the Scorecard. In some cases, test results were not available at the time of publication.**

To be eligible for the Scorecard, manufacturers must have:

- Completed the factory witness within 18 months of 2021
- Submitted BOMs to all test sequences in the PQP[1]
- Submitted at least two factory-witnessed PV module samples per test sequence.

Top Performers must have less than 2% degradation following each reliability test sequence. PAN performance is determined using PVsyst simulations; Top Performers must finish in the top quartile of energy yield.

[1] *Only characterizations for PAN files and IAM profiles are optional.*

## Industry Perspective: Models, BOMs and the PV Module Supply Chain

PV modules sold under the exact same model type can have completely different BOMs. As long as all materials are listed in the model's IEC certification report, manufacturers can mix and match key components, including cells and backsheets. As an ISO/IEC 17020:2012-accredited inspection body specialized in photovoltaics and energy storage, Senergy Technical Services (STS) inspectors have witnessed these BOM variations in factories all over the world, for more than 10 years.

While the practice of supplying one BOM for certification testing and another BOM to the market raises quality concerns, supply chain diversification is necessary for a dependable global supply of PV modules. Through the past year, market turmoil caused by wide-ranging factors including COVID-related factory closures, new trade policies, new environmental or social responsibility requirements, and even shortages of glass or polysilicon, have highlighted the fragility of the PV module supply chain.

STS completed GWs of PV module inspections in Q1 2021 and found that **nearly a third of the projects exhibited at least one BOM-related non-conformity.**

**Contributed by:**
**Frédéric Dross, Vice President, Strategic Development, STS**

STS Beyond inspection

*STS inspector examines a module during a production audit. Photo courtesy of STS.*

# Thermal Cycling Overview

## Key Takeaways

- **Strong thermal cycling (TC) results continued to be a trend in the 2021 Scorecard test population with a median power degradation of -0.86% after TC600, though not all modules were Top Performers.**
- **Compared to PVEL's historic PQP results, monocrystalline wafers and Passivated Emitter and Rear Contact (PERC) cells exhibit stronger TC performance than multicrystalline wafers and Aluminum Back Surface Field (Al-BSF) cells.**
- **For all the advantages of multi-busbar (MBB) modules, e.g., reduced power loss from microcracks and higher output power, improper soldering can lead to poor TC results. Three-, four- and five-busbar modules have thus far on average performed better in TC than MBB modules.**
- **Modules can meet the requirements for IEC 61215 after completing 200 thermal cycles but then exhibit significant degradation following the PQP's more rigorous TC600 benchmark.**
- **Bifacial TC results showed both glass//glass and glass//backsheet bifacial modules achieving Top Performer status, with the amounts of front-side and rear-side power degradation aligned.**

## Test Background

As fielded module temperatures rise and fall, the components expand and contract. With different thermal expansion coefficients, components can expand and contract at different rates in the same environmental conditions. This stresses the bonds between each PV module layer. Solder bond fatigue, for example, increases voltage drop in the module as current passes through a higher-resistance internal circuit, thus diminishing performance when the sun is at its brightest.

## Test Procedure

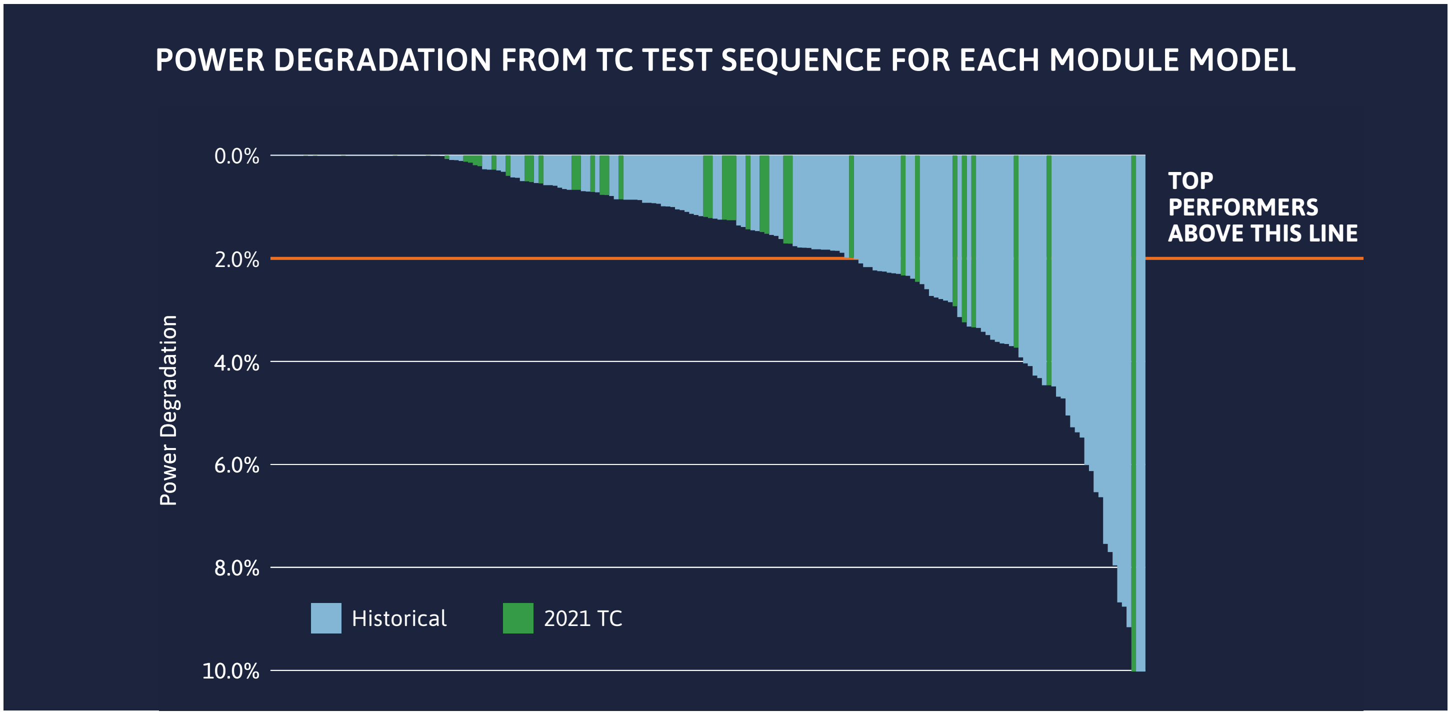
The thermal cycling test sequence subjects modules to extreme temperature swings in an environmental chamber where modules are chilled to -40°C, dwelled, then heated to 85°C, and dwelled again. While the temperature is increased, the modules are also subjected to maximum power current. The cycle repeats 200 times over three periods for a total of 600 cycles. IEC 61215 testing, by comparison, requires 200 cycles overall.

Note for Top Performers:
Manufacturers are listed in alphabetical order. The tested product is listed first. Variants for which the test results are representative are listed in parentheses. In some cases, test results were not available at the time of publication.

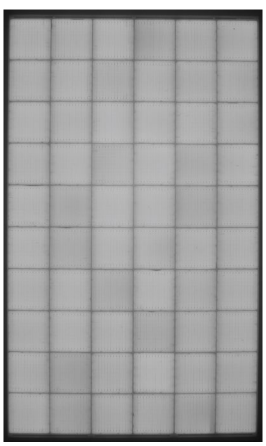
## Thermal Cycling Top Performers

| MANUFACTURER | MODEL TYPES |
|---|---|
| Adani/Mundra | ASB-7-AAA-n (ASB-6-AAA-n) ; ASB-7-AAA-p (ASB-6-AAA-p) |
| Astronergy | CHSM72M(DG)/F-BH-xxx (CHSM60M(DG)/F-BH-xxx) ; CHSM72M-HC-xxx (CHSM60M-HC-xxx) |
| Boviet | BVM6612M-xxxL-H-BF-DG (BVM6610M-xxxL-H-BF-DG) ; BVM6612M-xxxL-H-HC-BF-DG (BVM6610M-xxxL-H-HC-BF-DG) |
| ET Solar | ET-M672BHxxxTW (ET-M660BHxxxTW) |
| GCL | GCL-M3/72DH (GCL-M3/60DH) ; GCL-M3/72GDF (GCL-M3/60GDF) ; GCL-M3/72H (GCL-M3/60H) ; GCL-M6/72GDF (GCL-M6/60GDF) |
| Hyundai | HiS-SxxxGI |
| Jinko | JKMxxxM-72H-TV (JKMxxxM-72HL-TV, JKMxxxM-60H-TV, JKMxxxM-60HL-TV) |
| LONGi | LR4-72HBD-xxxM (LR4-60HBD-xxxM) ; LR4-72HIBD-xxxM (LR4-60HIBD-xxxM) ; LR4-72HIH-xxxM (LR4-60HIB-xxxM) ; LR4-72HPH-xxxM (LR4-60HPH-xxxM, LR4-60HPB-xxxM) ; LR6-72HPH-xxxM (LR6-60HPH-xxxM, LR6-60HPB-xxxM) |
| Maxeon/SunPower | SPR-Axxx-G-AC (SPR-MAX5-xxx-E3-AC, SPR-Axxx-BLK-G-AC, SPR-MAX5-xxx-BLK-E3-AC, SPR-Axxx, SPR-MAX5-xxx, SPR-Axxx-BLK, SPR-MAX5-xxx-BLK) ; SPR-P3-xxx-COM-1500 (SPR-P3-xxx-BLK) |
| Phono Solar | PSxxxM4GFH-24/TH |
| Q CELLS | Q.PEAK DUO L-G5.2 (Q.PEAK DUO G5, Q.PEAK DUO BLK-G5) ; Q.PEAK DUO BLK-G6+/SC (Q.PEAK DUO BLK-G6+, Q.PEAK DUO-G6+) ; Q.PEAK DUO-G7 (Q.PEAK DUO BLK-G7) ; Q.PEAK DUO L-G8.3 (Q.PEAK DUO BLK-G8+, Q.PEAK DUO-G8+) ; Q.PEAK DUO L-G8.3/BFG |
| REC Group | TP3M Black |
| Seraphim | SRP-xxx-BMA-BG |
| Silfab | SIL-xxxBL |

# Thermal Cycling Test Results




## An Example from the Lab



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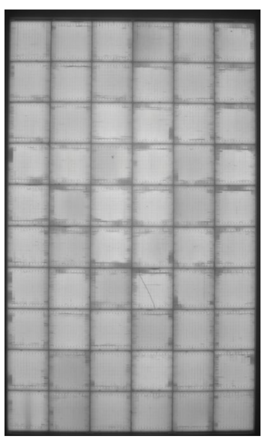
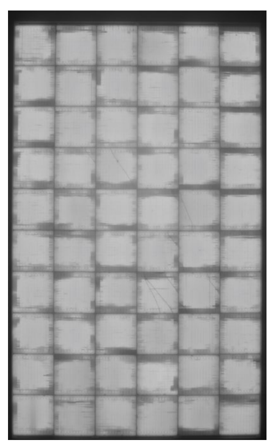
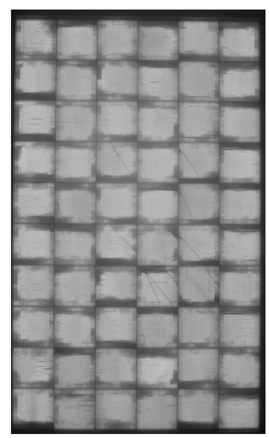


TC200



TC400

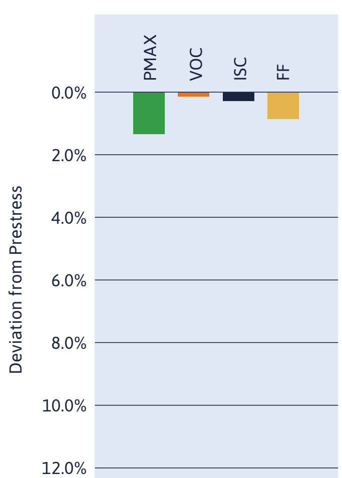


TC600

**See more data online**

**Example from the Field >>**

**Lessons learned from Failure >>**





# Damp Heat Overview

## Key Takeaways

- **PVEL's latest test results indicate that damp heat (DH) remains critical for identifying modules susceptible to moisture ingress, even though the industry has yet to reach consensus on the field relevancy of boron-oxygen (BO) destabilization that is observed in many PERC modules.**
- **30% of the Top Performers achieved less than 2% degradation before the 48-hour high-heat, high-current BO stabilization treatment after DH2000. The remaining Top Performers achieved less than 2% degradation after power loss recovery from BO stabilization. Pre- and post-stabilization results are provided in PQP reports to delineate reversible BO-induced degradation from irreversible DH-induced degradation.**
- **In the provided lab example, a module completed the 1,000-hour DH test duration with less than 5% power degradation, a result that passes IEC 61215. After another 1,000 hours, power loss soared to 11.7% and did not fully recover after BO stabilization.**
- **DH results for glass//glass modules are comparable to glass//backsheet designs, showing that manufacturers have generally overcome early issues with glass//glass designs. For bifacial modules, the amounts of front-side and rear-side power degradation are similar.**

## Test Background

PV modules experience periods of high temperature and humidity not only in tropical and subtropical regions but also in moderate climates. In these conditions, inferior quality components or substandard lamination procedures can lead to degradation or premature failure. The damp heat test replicates degradation and failure mechanisms that can occur in the field.

## Test Procedure

The damp heat test subjects modules to a constant 85°C and 85% relative humidity in an environmental chamber for two periods of 1,000 hours—twice the duration required for IEC certification. The combination of high heat and intense moisture stresses the PV module layers. An environment with high temperature and no current can lead to destabilizing passivated BO complexes within some PERC cells. In the current PQP, to explore this phenomenon PVEL added a post-DH2000 BO stabilization process.

A Note for Top Performers:
Manufacturers are listed in alphabetical order. The tested product is listed first. Variants for which the test results are representative are listed in parentheses. In some cases, test results were not available at the time of publication.

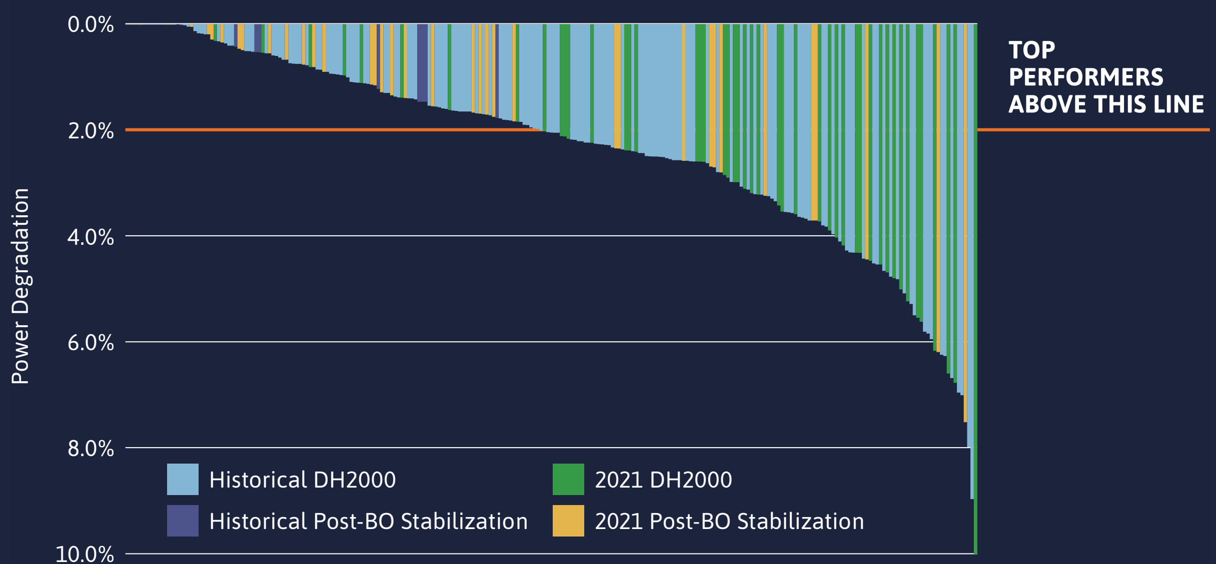
## Damp Heat Top Performers

| MANUFACTURER | MODEL TYPES |
|---|---|
| Adani/Mundra | ASB-7-AAA-p* (ASB-6-AAA-p*) |
| Boviet | BVM6612M-xxxL-H-BF-DG (BVM6610M-xxxL-H-BF-DG) ; BVM6612M-xxxL-H-HC-BF-DG* (BVM6610M-xxxL-H-HC-BF-DG*) |
| ET Solar | ET-M672BHxxxTW (ET-M660BHxxxTW) |
| GCL | GCL-M3/72DH* (GCL-M3/60DH*) ; GCL-M3/72GDF* (GCL-M3/60GDF*) |
| HT-SAAE | HT72-156M(V) |
| Hyundai | HiS-SxxxGI* |
| JA Solar | JAM72S09-xxx/PR (JAM60S09-xxx/PR) ; JAM72S10-xxx/MR (JAM78S10-xxx/MR, JAM60S10-xxx/MR) |
| LG Electronics | LGxxxN1C-N5* ; LGxxxN1C-V5* |
| LONGi | LR4-72HBD-xxxM* (LR4-60HBD-xxxM*) |
| Maxeon/SunPower | SPR-Axxx-G-AC (SPR-MAX5-xxx-E3-AC, SPR-Axxx, SPR-MAX5-xxx) ; SPR-Axxx-COM (SPR-MAX5-xxx-COM) ; SPR-P3-xxx-COM-1500* |
| Q CELLS | Q.PEAK DUO BLK-G5* ; Q.PLUS DUO L-G5.2* (Q.PLUS DUO-G5*) ; Q.PEAK DUO L-G5.2* (Q.PEAK DUO-G5*) ; Q.PEAK DUO BLK-G6+/SC* (Q.PEAK DUO BLK-G6+*, Q.PEAK DUO L-G6.2*) ; Q.PEAK DUO-G7* (Q.PEAK DUO L-G7*) ; Q.PEAK DUO L-G8.3* (Q.PEAK DUO-G8+*) |
| REC Group | Alpha* ; Alpha Black* ; TP3M Black |
| Seraphim | SRP-xxx-BMA-BG* |
| Silfab | SIL-xxxBL* |
| Talesun | TD6G72M-xxx (TD6G60M-xxx) |
| VSUN | VSUNxxx-72MH* (VSUNxxx-60MH*) |

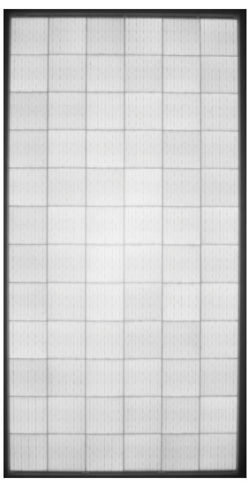
***Top-performing result achieved after BO stabilization.***
*PVEL contacted six industry experts for opinions on the field relevancy of BO destabilization. They agreed BO destabilization will not occur in the field within the first 10 years. Opinions on the long-term impacts were mixed. Go online to learn more.*

# Damp Heat Test Results

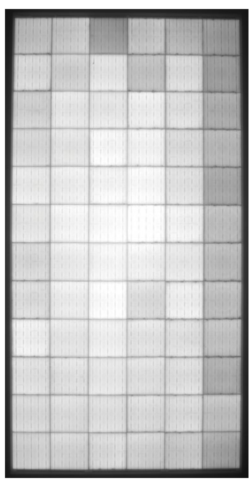
POWER DEGRADATION FROM DH TEST SEQUENCE FOR EACH MODULE MODEL



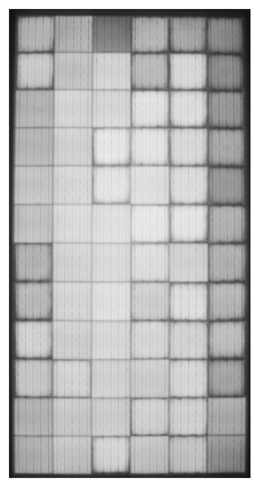

## An Example from the Lab



Initial



DH1000



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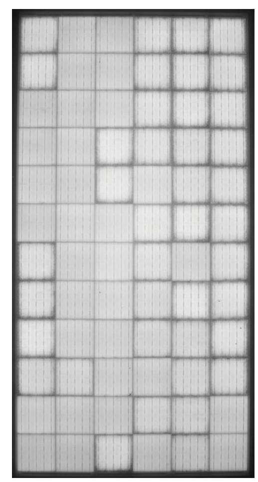
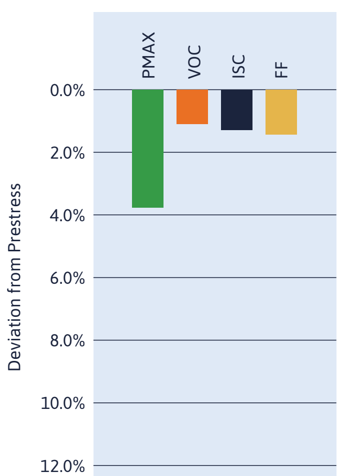


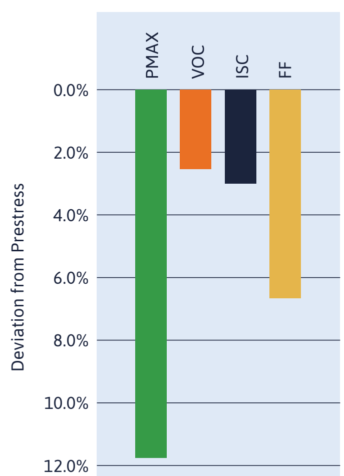
Post BO

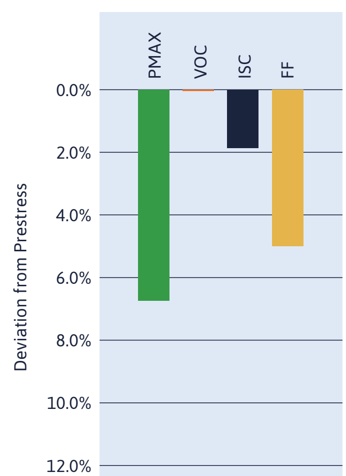
**See more data online**

[Example from the Field >>]

[Lessons learned from Failure >>]



# Mechanical Stress Sequence Overview

## Key Takeaways

- Module susceptibility to cell cracking depends on many factors and results are nuanced. In general, PVEL has found that:
  - half-cut cells perform better than full cells;
  - 120-cell designs perform better than 144-cell designs;
  - monocrystalline cells perform better than multicrystalline cells;
  - multi-busbar cells perform better than 3BB, 4BB or 5BB cells;
  - interdigitated back contact (IBC), cadmium telluride (CdTe) thin film, and glass//glass module technologies have also shown minimal degradation.
- Modules can experience significant cell cracking during MSS testing using the ideal mounting: rails running the width of the module in one-quarter segments on either end. For these modules alternative configurations used in trackers and roof mounts are very likely to exhibit a greater degree of cell cracking.
- The installation manuals for select modules do not include PVEL's standard MSS mounting configuration. These modules achieved Top Performer results when tested according to the manufacturer's manual. PVEL encourages review of PQP test reports and installation manuals for mounting guidance.
- Compared to PVEL's historical database of DML+TC50+HF10 results, the results of median power loss from MSS, which adds SML to the start of the sequence, increased by almost 50%.

## Test Background

Excessive thermal and mechanical stress can cause microcracks to form in PV cells. Stress can occur during: cell soldering, lamination, and other module manufacturing processes; exposure to temperature fluctuations, wind, snow, hail, and other environmental conditions; and/or physical damage in transportation, installation, or maintenance. If cracks restrict the flow of current through the cell, modules can produce less energy. They can also form hotspots, introducing safety risks.

## Test Procedure

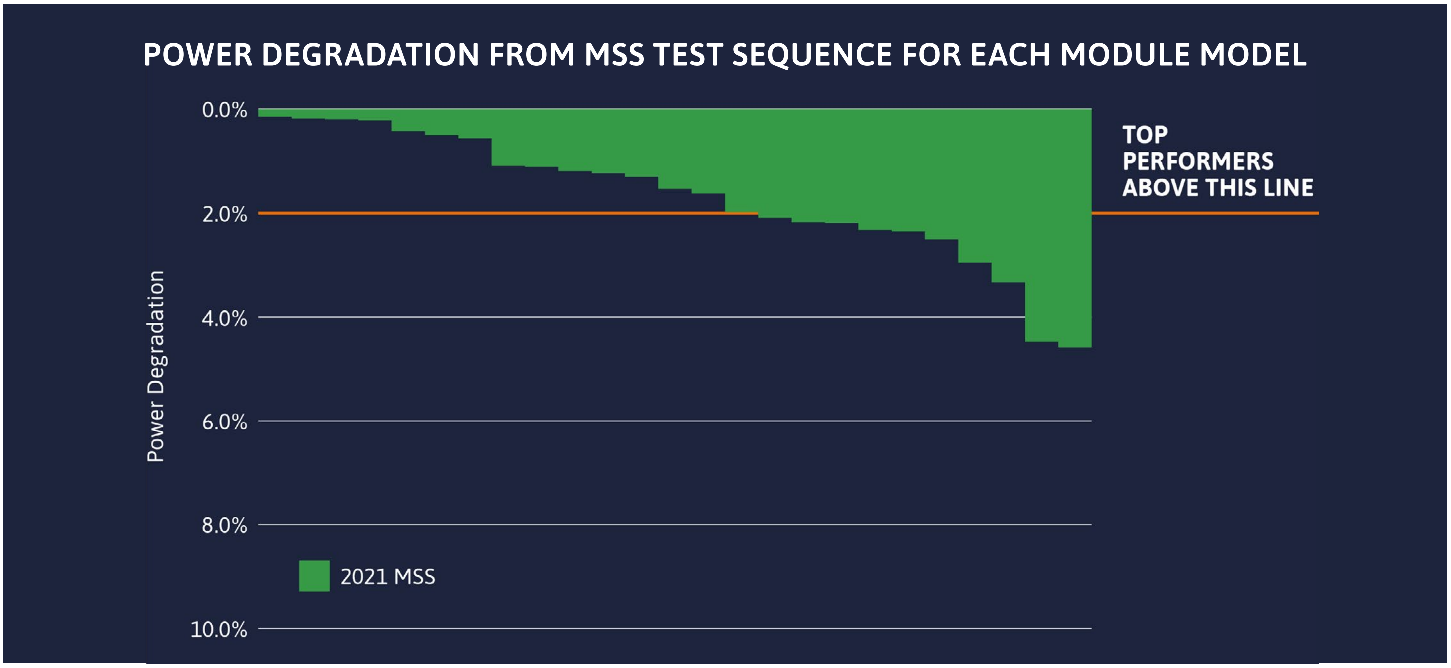
MSS, added to PVEL's PQP in 2019, combines tests for static mechanical load (SML), dynamic mechanical load (DML), thermal cycling, and humidity freeze to create, articulate and propagate cracks in susceptible modules. For SML, modules undergo three rounds of one-hour downforce and one-hour upforce at 2,400 Pa. For DML, modules are subjected to 1,000 cycles of alternating positive and negative loading at 1,000 Pa. To simulate environmental stress, modules undergo 50 thermal cycles then 10 cycles of humidity freeze.

## MSS Top Performers

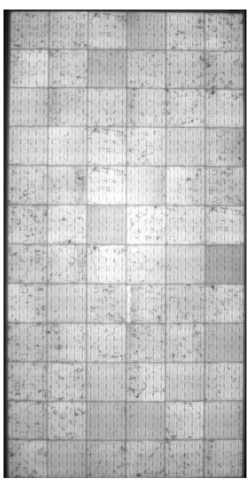
| MANUFACTURER | MODEL TYPES |
|---|---|
| Boviet | BVM6612M-xxxL-H-BF (BVM6610M-xxxL-H-BF) ; BVM6612M-xxxL-H-BF-DG (BVM6610M-xxxL-H-BF-DG) ; BVM6612M-xxxL-H-HC-BF-DG (BVM6610M-xxxL-H-HC-BF-DG) |
| ET Solar | ET-M672BHxxxTW (ET-M660BHxxxTW) |
| First Solar | FS-6xxxA |
| Jinko | JKMxxxM-7RL3-V |
| LG Electronics | LGxxxN1C-N5 (LGxxxN1C-V5) ; |
| LONGi | LR4-60HPB-xxxM ; LR4-72HBD-xxxM (LR4-60HBD-xxxM) ; LR4-72HPH-xxxM (LR4-60HPH-xxxM) |
| Maxeon/SunPower | SPR-Axxx-G-AC (SPR-MAX5-xxx-E3-AC, SPR-Axxx, SPR-MAX5-xxx) |
| Phono Solar | PSxxxM4GFH-24/TH |
| Q CELLS | Q.PEAK DUO L-G5.2 ; Q.PEAK DUO BLK ML-G9+ |
| Seraphim | SRP-xxx-BMA-BG |

Note for Top Performers:
Manufacturers are listed in alphabetical order. The tested product is listed first. Variants for which the test results are representative are listed in parentheses. In some cases, test results were not available at the time of publication.

# Mechanical Stress Sequence Test Results




## An Example from the Lab



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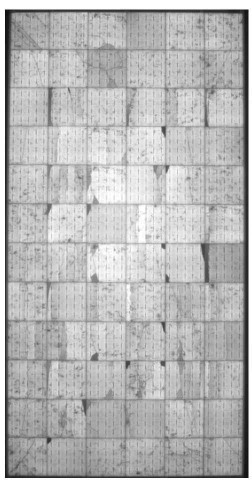
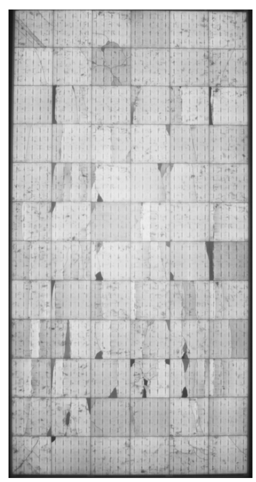
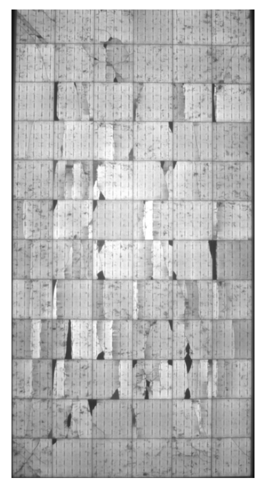


SML



DML

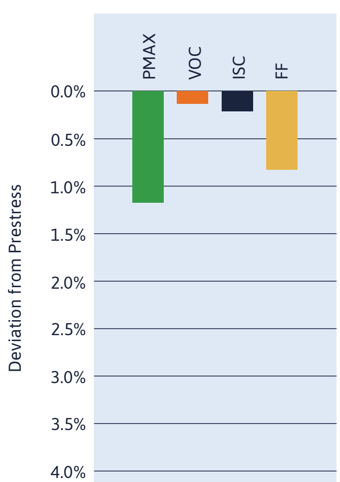


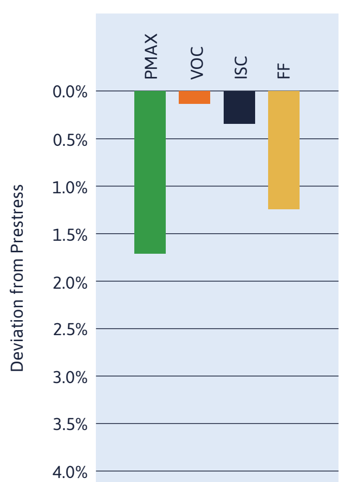
TC50+HF10

**See More Data Online:**

[Example from the Field >>]

[Lessons Learned from Failure >>]




# Potential-Induced Degradation (PID)

## Key Takeaways

- **Many module datasheets continue to advertise products as "PID resistant", yet both the median and average degradation from PID was higher in the 2021 Scorecard dataset than in the 2020 Scorecard dataset—the highest in PVEL's history.**
- **Manufacturers are producing more modules that are inherently susceptible to PID, and some are clearly struggling with mitigation.**
- **The results presented here are based on PID testing with negative voltage applied between the cells and the frame. The PQP also includes PID testing on two additional samples with positive voltage applied. These PID+ results are typically the same or better than the PID- results that are shown here.**
- **PID susceptibility of bifacial modules continues to be mixed. Many of the Top Performers are bifacial with both glass// glass and glass//backsheet configurations, yet there are bifacial modules with more than 4% front-side degradation. Rear-side degradation is also mixed, ranging from 0% to >15%. Some of this may be due to PID-polarization. More research is needed on the field-relevancy of this phenomenon.**
- **One solution to PID is through system design, including the use of specific grounding configurations or distributed electronics. PVEL recommends that developers and EPCs evaluate these alternative solutions if PID-resistant modules are not being procured for a project.**

## Test Background

PID can occur within weeks or even days of commissioning. It generally occurs when the internal PV electrical circuit is biased negatively in relation to ground. The voltage between the frame and the cells can cause sodium ions from the glass to drift toward the cell surface, which typically has a silicon nitride (SiN) anti-reflective coating. If pinholes, also known as shunts, in this coating are large enough to allow sodium ions to enter the cell, then performance can be irreparably impaired. Additionally, this voltage can cause a buildup of static charge, which can also reduce performance, although this effect is typically reversible.

## Test Procedure

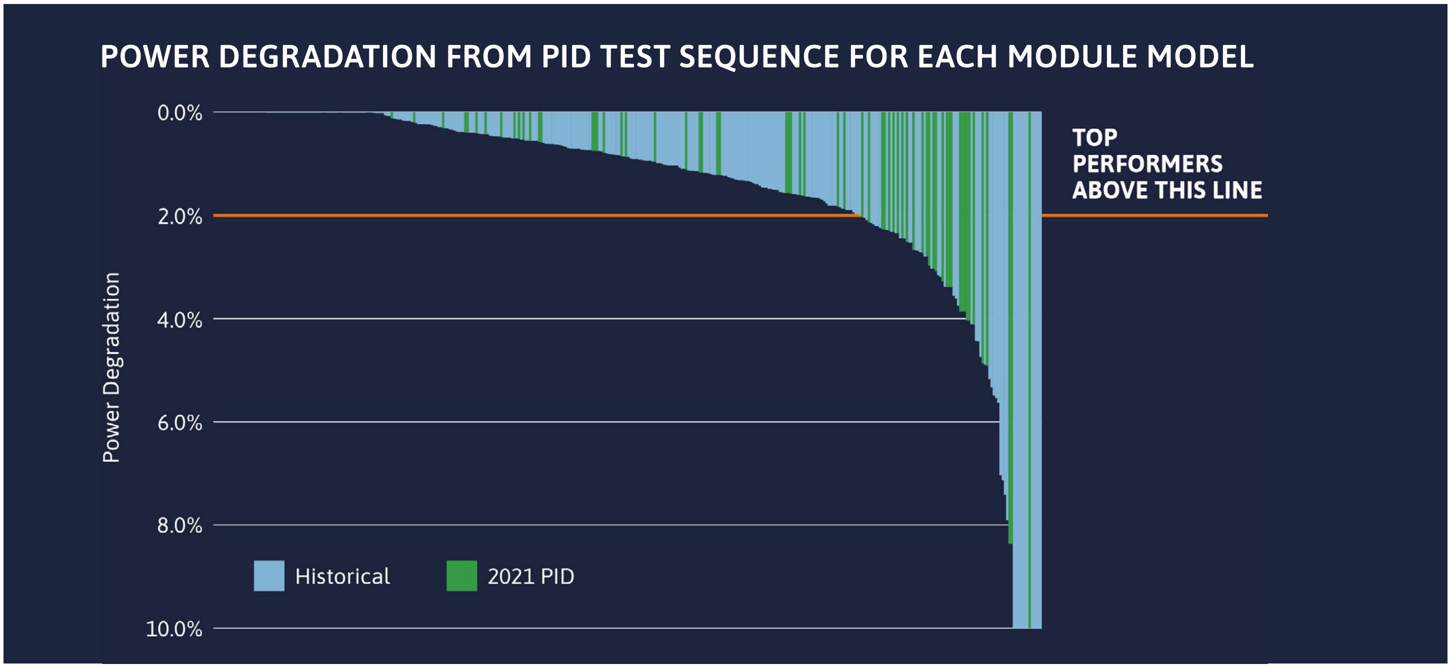
Once the module is placed in an environmental chamber, the voltage bias equal to the maximum system voltage rating of the module (-1000V or -1500V) is applied with 85°C and 85% relative humidity for two cycles of 96 hours. These temperature, moisture, and voltage bias conditions help evaluate possible degradation and failure mechanisms related to increased leakage currents.

## PID Top Performers

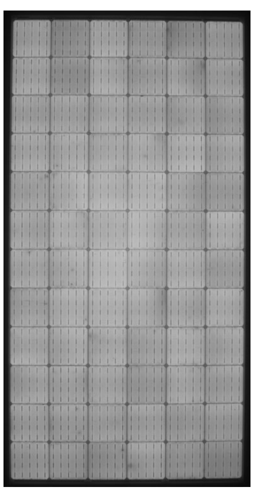
| MANUFACTURER | MODEL TYPES |
|---|---|
| Adani/Mundra | ASB-7-AAA-p (ASB-6-AAA-p) |
| Boviet | BVM6612M-xxxL-H-BF (BVM6610M-xxxL-H-BF); BVM6612M-xxxL-H-BF-DG (BVM6610M-xxxL-H-BF-DG) |
| DMEGC | DMxxxM6-G72HST (DMxxxM6-G60HST) |
| ET Solar | ET-M672BHxxxTW (ET-M660BHxxxTW) |
| First Solar | FS-6xxxA |
| HHDC | SPICN6(MDF)-72-xxx ; BIH (SPICN6(MDF)-60-xxx/BIH) |
| JA Solar | JAM72S09-xxx/PR (JAM60S09-xxx/PR) |
| Jinko | JKMxxxM-72H-TV (JKMxxxM-72HL-TV, JKMxxxM-60H-TV, JKMxxxM-60HL-TV) ; JKMxxxM-7RL3-V (JKMxxxM-6RL3, JKMxxxM-6RL3-B) |
| Jolywood | JW-HD144N-xxx (JW-HD120N-xxx) |
| LG Electronics | LGxxxN1C-N5 |
| LONGi | LR4-72HBD-xxxM (LR4-60HBD-xxxM) ; LR4-72HIBD-xxxM (LR4-60HIBD-xxxM) ; LR6-72HPH-xxxM (LR6-60HPH-xxxM, LR6-60HPB-xxxM) |
| Maxeon/SunPower | SPR-Axxx-G-AC (SPR-MAX5-xxx-E3-AC, SPR-Axxx-BLK-G-AC, SPR-MAX5-xxx-BLK-E3-AC, SPR-Axxx, SPR-MAX5-xxx, SPR-Axxx-BLK, SPR-MAX5-xxx-BLK) ; SPR-P3-xxx-COM-1500 (SPR-P3-xxx-BLK, SPR-P3-xxx-BLK-E3-AC) |
| Phono Solar | PSxxxM4GFH-24/TH |
| Q CELLS | Q.PEAK DUO BLK-G5 ; Q.PLUS DUO L-G5.2 (Q.PLUS DUO-G5) ; Q.PEAK DUO L-G5.2 (Q.PEAK DUO-G5) ; Q.PEAK DUO BLK-G6+ (Q.PEAK DUO-G6+, Q.PEAK DUO BLK-G6+/AC, Q.PEAK DUO L-G6.2); Q.PEAK DUO BLK-G6+/SC ; Q.PEAK DUO-G7 (Q.PEAK DUO L-G7) ; Q.PEAK DUO BLK ML-G9+ (Q.PEAK DUO XL-G9.2) |
| REC Group | Alpha (Alpha Black) ; TP3M Black |
| Risen Energy | RSM144-7-xxxBMDG (RSM120-7-xxxBMDG) |
| Silfab | SIL-xxxBL |
| Talesun | TD6G72M-xxx (TD6G60M-xxx) |
| Vikram | VSMDHT.72.AAA.05 (VSMDHT.78.AAA.05, VSMDHT.60.AAA.05) |

Note for Top Performers: Manufacturers are listed in alphabetical order. The tested product is listed first. Variants for which the test results are representative are listed in parentheses. In some cases, test results were not available at the time of publication.

# PID Test Results




## An Example from the Lab



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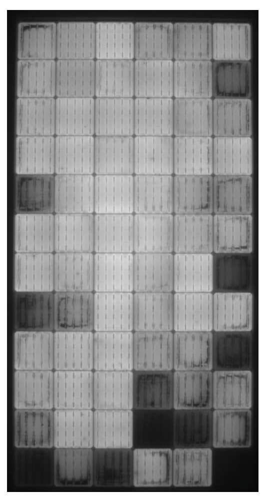
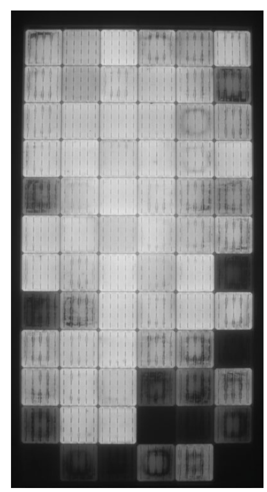


PID96

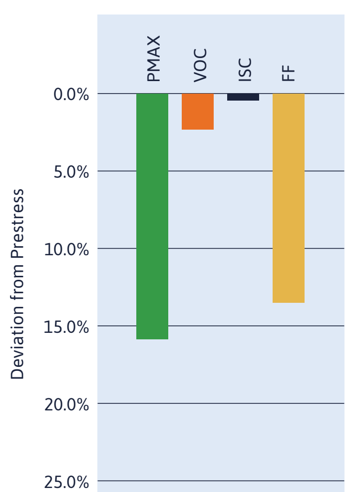


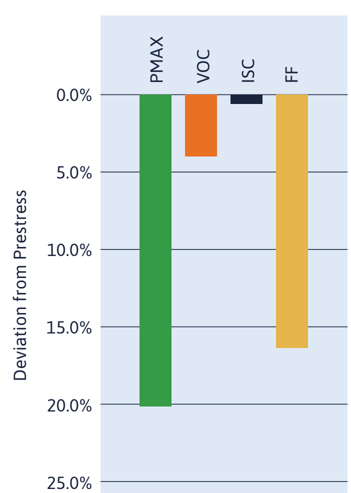
PID192

**See more Data Online**

[Example from the Field >>]

[Lessons learned from Failure >>]



# LID + LETID Overview

## Key Takeaways

- **The impact of LID on Al-BSF cells is well-understood, but the industry lacks clarity for PERC technology, which is also affected by LETID.**
- **Test results for both boron- and gallium-doped PERC modules show that LID and LETID can be solved, but it is possible that new degradation modes will emerge in the field over time.**
- **Procuring modules with low LID and LETID rates increases the value of a project; the results from LID and LETID testing are direct inputs for energy forecasts and financial models.**
- **Independent engineers (IEs) model LID and LETID behaviors inconsistently. Some IEs combine LID and LETID, some model LETID recovery over time, and a range of different values are used for default assumptions.**

## Test Background

LID generally refers to the rapid power loss caused by unstable boron-oxygen compounds that occurs when p-type crystalline modules are first exposed to sunlight. Al-BSF module manufacturers historically guaranteed 3% year-one degradation for monocrystalline modules and 2.5% for multicrystalline modules. The outlook for modern PERC and PERT cells is much less clear. They are treated before module manufacturing, leading to historically low LID, but these treatments can increase LETID susceptibility.

LETID affects advanced multicrystalline and monocrystalline cell architectures. It has been shown to materialize when cells reach temperatures over 40°C while operating, which not only occurs in hot environments but also in temperate regions during high irradiance. Degradation eventually stabilizes and can recover over time, but regeneration rates vary.

## Test Procedure

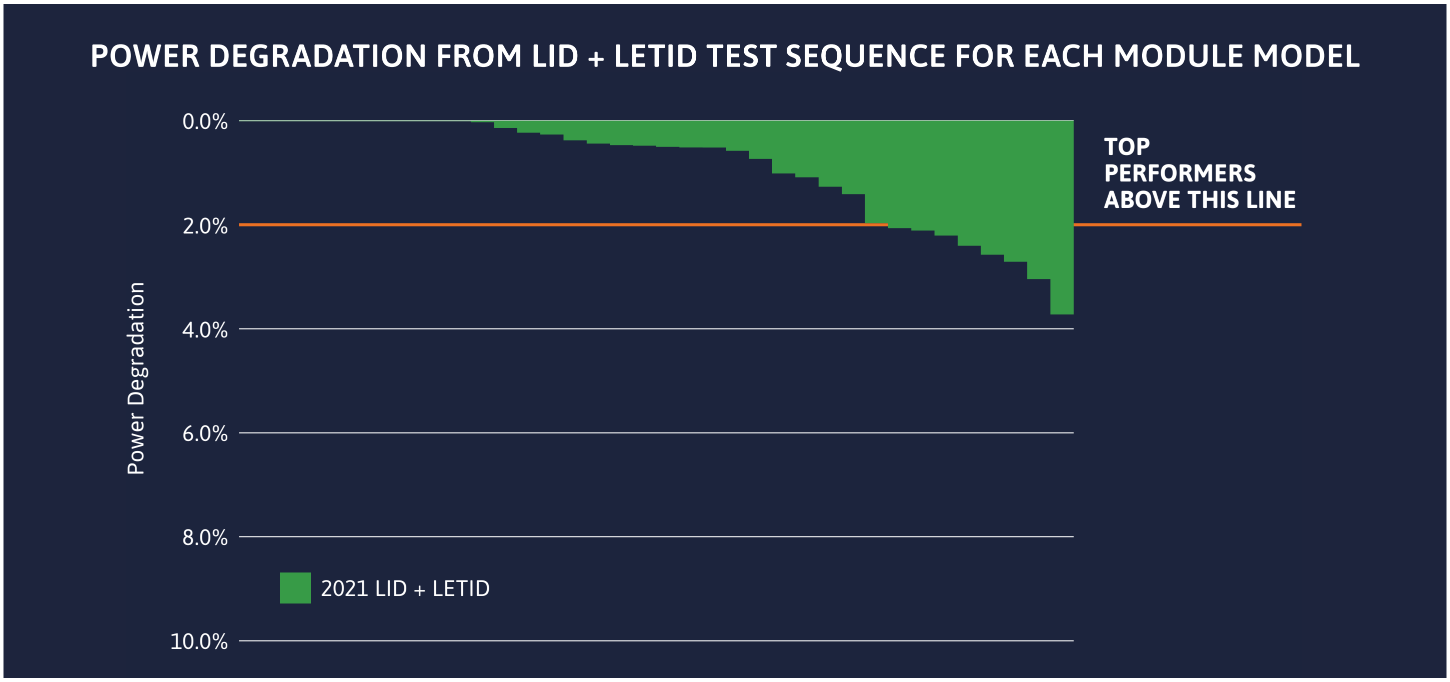
PVEL tests a statistically significant 17 samples for LID in the PQP. Modules are placed outdoors and connected to an inverter to operate at maximum power point. They are exposed to repeated rounds of light soaking and flash testing until stability is reached per IEC 61215:2016. To measure LETID, two of the post-LID modules are placed in an environmental chamber at 75°C while connected to a power supply and injected with a low current for 486 hours with characterizations every 162 hours. This simulates module operation in full sun at maximum power point. The test conditions are designed to slowly approach maximum degradation, so as not to trigger additional degradation mechanisms.

Note for Top Performers:
Manufacturers are listed in alphabetical order. The tested product is listed first.
Variants for which the test results are representative are listed in parentheses.
In some cases, test results were not available at the time of publication.

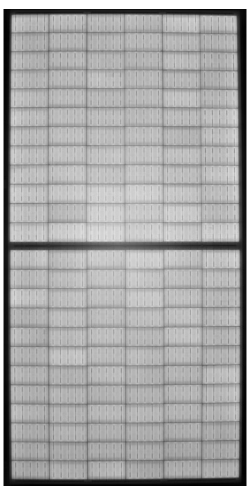
## LID+LETID Top Performers

| MANUFACTURER | MODEL TYPES |
|---|---|
| Adani/Mundra | ASB-7-AAA-n (ASB-6-AAA-n) |
| Astronergy | CHSM72M(DG)/F-BH-xxx (CHSM60M(DG)/F-BH-xxx) ;<br>CHSM72M-HC-xxx (CHSM60M-HC-xxx) |
| Boviet | BVM6612M-xxxL-H (BVM6610M-xxxL-H) ;<br>BVM6612M-xxxS-H-HC-BF-DG (BVM6610M-xxxS-H-HC-BF-DG) |
| ET Solar | ET-M660BHxxxBB (ET-M672BHxxxBB) ;<br>ET-M672BHxxxTW (ET-M660BHxxxTW) |
| HHDC | SPICN6(MDF)-72-xxx ;<br>BIH (SPICN6(MDF)-60-xxx/BIH) |
| HT-SAAE | HT72-156M(V) (HT72-156M, HT60-156M) |
| Hyundai | HiS-SxxxGI |
| JA Solar | JAM72S10-xxx/MR (JAM78S10-xxx/MR, JAM60S10-xxx/MR, JAM60S17-xxx/MR) |
| Jinko | JKMxxxM-72H-TV (JKMxxxM-72HL-TV, JKMxxxM-60H-TV, JKMxxxM-60HL-TV) ;<br>JKMxxxM-7RL3-V (JKMxxxM-6RL3, JKMxxxM-6RL3-B) |
| Jolywood | JW-HD144N-xxx (JW-HD120N-xxx) |
| LG Electronics | LGxxxN2W-V5 (LGxxxN1C-V5) ;<br>LGxxxN1C-N5 ;<br>LGxxxQ1C-A6 |
| LONGi | LR4-72HIH-xxxM (LR4-60HIB-xxxM) ;<br>LR4-72HPH-xxxM (LR4-60HPH-xxxM, LR4-60HPB-xxxM) |
| Maxeon/ SunPower | SPR-Axxx-G-AC (SPR-MAX5-xxx-E3-AC, SPR-Axxx-BLK-G-AC, SPR-MAX5-xxx-BLK-E3-AC, SPR-Axxx, SPR-MAX5-xxx, SPR-Axxx-BLK, SPR-MAX5-xxx-BLK, SPR-Axxx-COM, SPR-MAX5-xxx-COM) |
| Phono Solar | PSxxxM4GFH-24/TH |
| Q CELLS | Q.PEAK DUO L-G5.2 (Q.PEAK DUO-G5, Q.PEAK DUO BLK-G5) ;<br>Q. PEAK DUO BLK-G6+ (Q.PEAK DUO-G6+, Q.PEAK DUO BLK-G6+/AC, Q.PEAK DUO L-G6.2, Q.PEAK DUO BLK-G6+/SC) ;<br>Q.PEAK DUO L-G8.3/BFG ;<br>Q.PEAK DUO BLK ML-G9+ (Q.PEAK DUO XL-G9.2) |
| REC Group | Alpha (Alpha Black) ;<br>TP3M Black |
| Risen Energy | RSM144-7-xxxBMDG (RSM120-7-xxxBMDG) |
| Talesun | TD6G72M-xxx (TD6G60M-xxx) |
| Trina Solar | TSM-xxxDE15M(II) (TSM-xxxDD06M(II)) |

# LID + LETID Test Results




## An Example from the Lab



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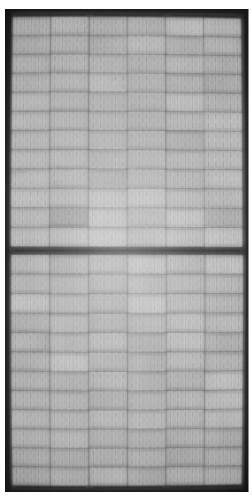

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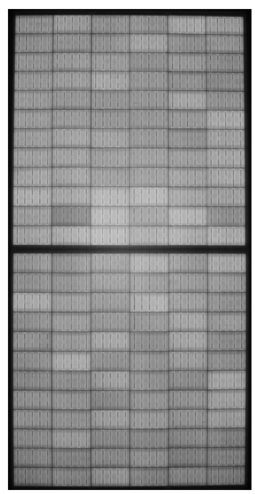
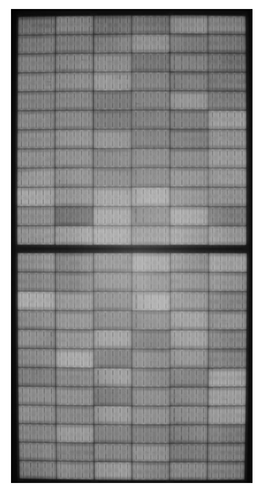


LETID168

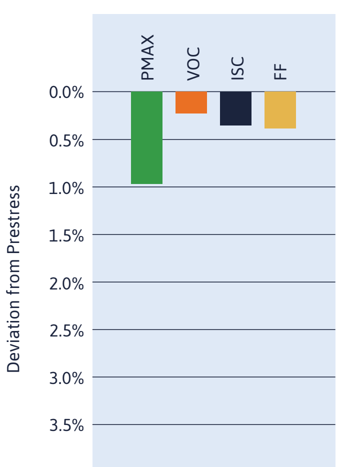


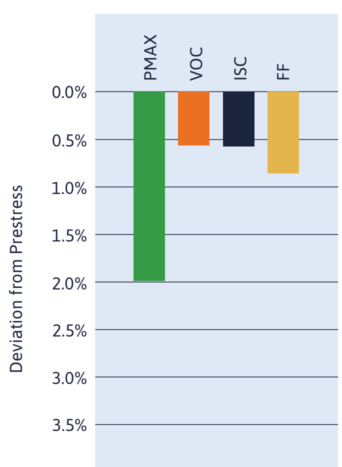
LETID486

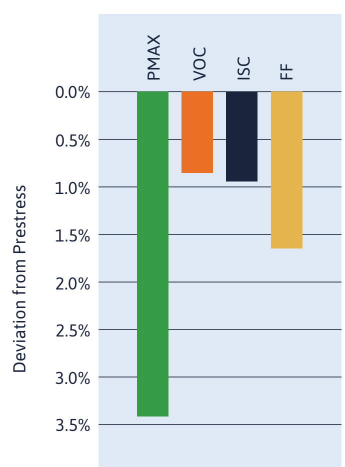
**See more data online:**

**LID + LETID in Practice >>**

**Lessons Learned from Failure >>**



# PAN Performance Overview

## Key Takeaways

- **Module performance continues to improve as shown by PVEL's historical PAN test results. Relative low light efficiency is increasing each year as is power output at high temperatures.**
- **All 2021 PAN Top Performers are bifacial modules because of the energy yield boost from their rear-sides. The median bifacial energy generation was 7.3% higher than the median for monofacial for Las Vegas and 2.3% higher than the median for Boston.**
- **Bifacial performance varied between +1.2% and -1.1% from median for Las Vegas and +1.6% and -0.6% from median for Boston. For monofacial modules the range of performance was larger: +2.5% to -1.3% from median for Las Vegas, and +1.4% to -1.7% for Boston.**
- **To put these values in context, a 1% change in performance can have a significant impact on project profitability, especially when that performance difference directly informs the energy models that determine project valuations.**
- **About half of the bifacial modules PVEL tested do not include a bifaciality specification on the datasheet. When this value was specified, 20% of BOMs had a PVEL-measured bifaciality at least 5% lower than claimed by the manufacturer.**
- **PVEL's PAN files have strong agreement with field performance as shown when analyzing measured versus modelled results.**

## Test Background

In PVsyst, an industry standard modeling program for predicting PV project performance, PAN files model irradiance- and temperature-dependent behavior of PV modules. Module datasheet specifications can be used to generate a functional PAN file but may not define all module performance parameters sufficiently for the full range of potential irradiance and temperature conditions. PVEL measures these conditions in the lab to provide more accurate modelling inputs.

## Test Procedure

Three identical PV modules are tested across a matrix of operating conditions per IEC 61853-1, ranging in irradiance from 100 W/m2 to 1100 W/m$^2$ and ranging in temperature from 15°C to 75°C. A custom PAN file is then created with PVsyst's model parameters optimized for close agreement between PVsyst's modeled results and PVEL's measurements across all conditions.

To better illustrate performance from optimized PAN files, each PAN report includes two site simulation results: a 1 MW site in a temperate climate at a 0° tilt (in Boston, USA), and a 1 MW site in a desert climate at 20° tilt (in Las Vegas, USA).

## PAN Performance Top Performers

| MANUFACTURER | NAME |
|---|---|
| Astronergy | CHSM72M(DG)/F-BH-xxx |
| Boviet | BVM6610M-xxxL-H-BF ; BVM6612M-xxxL-H-BF-DG |
| ET Solar | ET-M672BHxxxTW |
| GCL | GCL-M6/72GDF |
| LONGi | LR4-72HBD-xxxM |
| Seraphim | SRP-xxx-BMA-BG |

Note for Top Performers:
Manufacturers are listed in alphabetical order. The tested product is listed first. Variants for which the test results are representative are listed in parentheses. In some cases, test results were not available at the time of publication.

The Top Performers listed are module types whose PVsyst simulations for the Las Vegas or Boston site resulted in a kWh/kWp energy yield within the top quartile of all eligible results. The data presented here is only from PVEL's PAN testing as part of a PQP where the samples are factory witnessed.

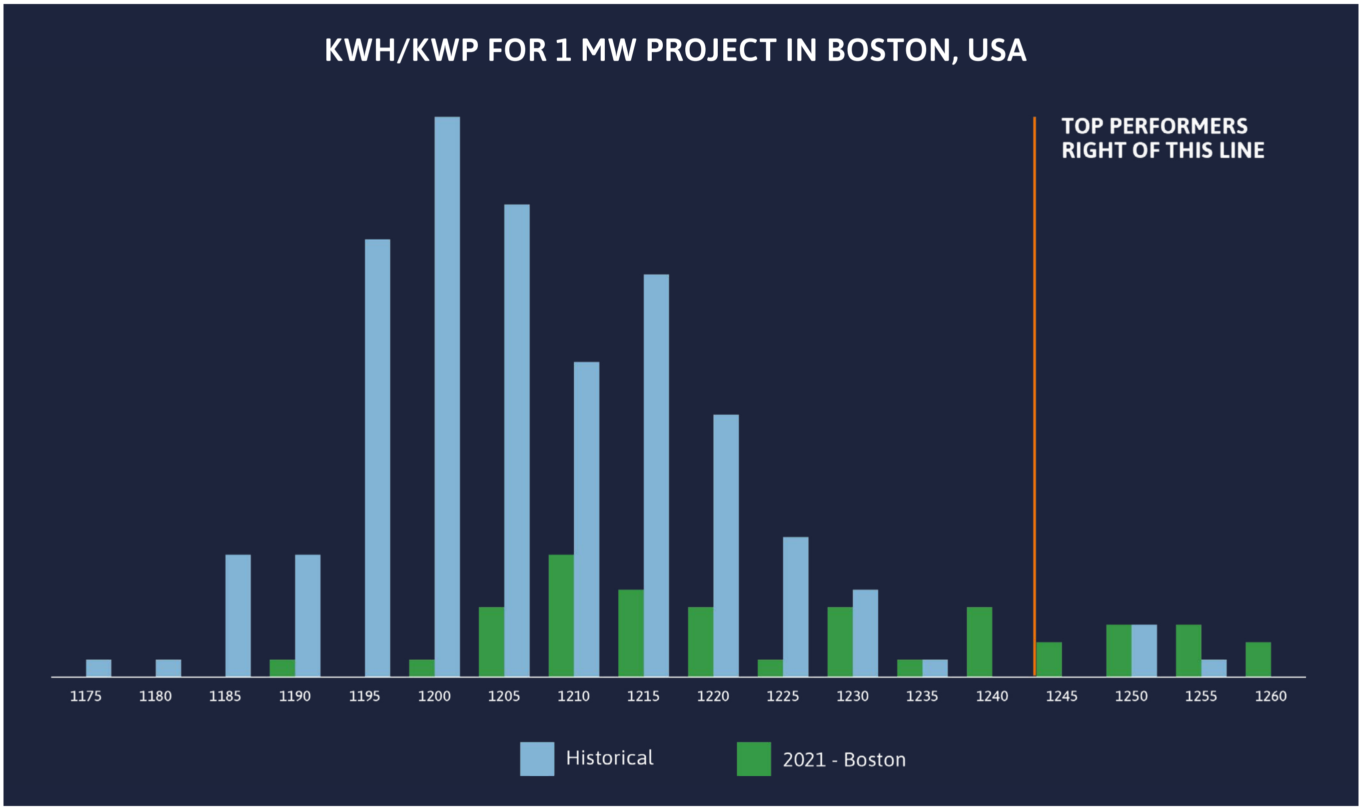
**See more data online:**

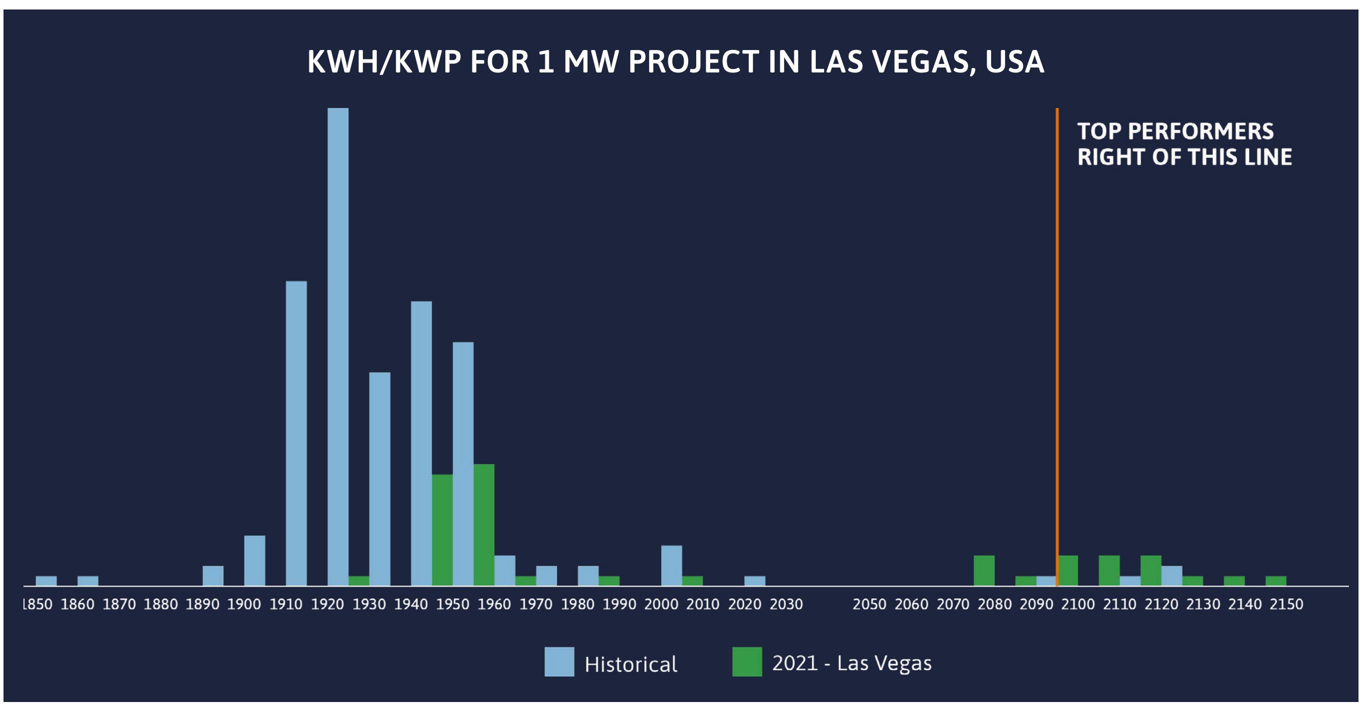
[Temperature Coefficients over Time by Technology >>]

[Temperature vs. Irradiance >>]

[PAN File Validation >>]

# PAN Performance Results



# Backsheet Durability Sequence

## Spotlight on Yellowing

**Widespread reports of backsheet failures in fielded modules prompted PVEL to introduce the Backsheet Durability Sequence (BDS) to the PQP in 2019. PVEL is pleased to share that no catastrophic backsheet cracking failures have occurred in PQP testing to date.**

**However, it is important to note that PQP participants choose which of their BOMs are factory witnessed and submitted for PQP testing. It is also important to note that less than 10% of commercially available backsheet models have completed BDS testing.**

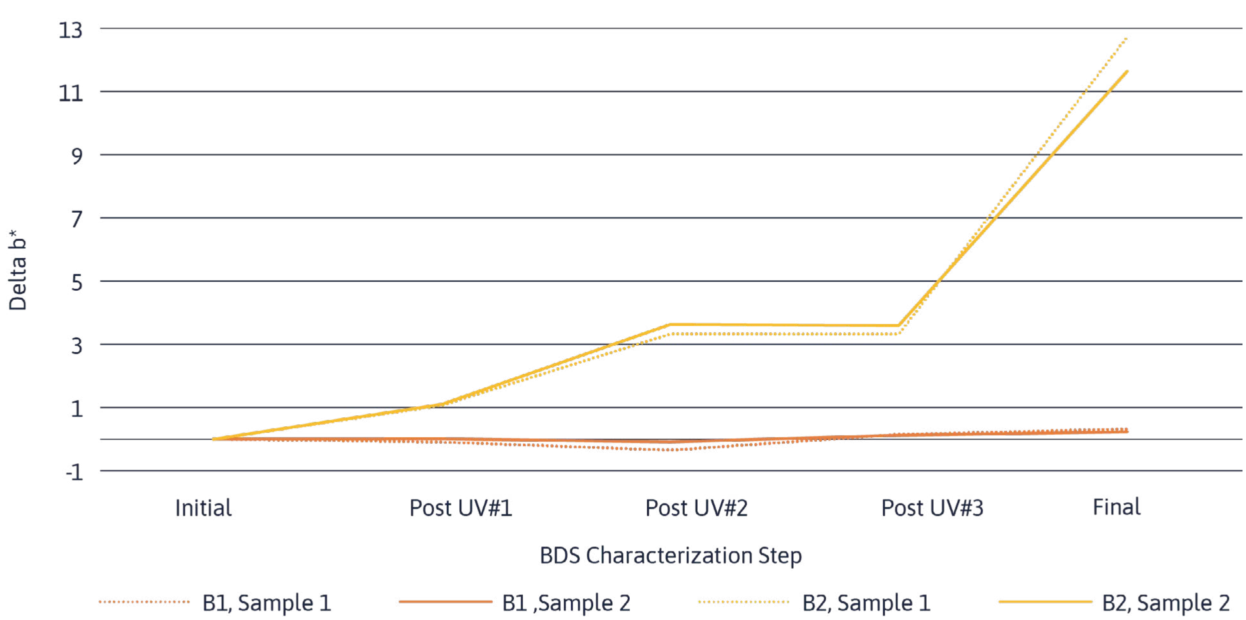
**After module certification testing, manufacturers are free to use any of the 100+ backsheet models on the market in commercially available products. Some will suffer failures, and it is well-documented that certification testing does not identify failure-prone backsheets. Specifying PQP-tested BOMs with strong BDS results will help ensure that backsheets and modules perform as anticipated.**

### Test Procedure

During BDS PVEL performs colorimeter measurements at ten different backsheet locations for two identical samples per BOM. These measurements use the Commission Internationale de l'Eclairage (CIE) L*a*b* coordinate system, with b* representing the yellow/blue coordinate. As yellowness increases so does the b* value. Calculating the delta b* from the average initial measurement throughout the course of BDS helps quantify the change in yellowness.

### An Example from the Lab

The graph below shows examples of two backsheet types. One sample has minimal change in the b* coordinate while the other backsheet type yellows significantly. There were no signs of material cracking in the yellowed samples, but it may still be cause for concern. Yellowing can be indicative of material degradation, but not always.



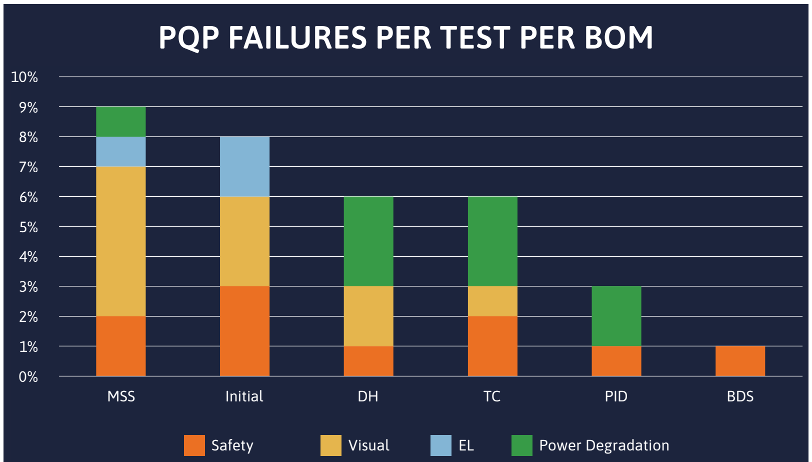

### Best Practices

**When BDS reports expose cases of yellowness PVEL recommends that module purchasers perform additional diligence. In these cases the module manufacturer should provide evidence that despite their backsheet's discoloration it will perform reliably for the expected module lifetime.**

# PQP Failures

## Key Takeaways

- **26% of BOMs eligible for this year's Scorecard had at least one failure compared to 20% in 2020.**
- **One in three manufacturers tested experienced junction box failures versus one in five last year. The majority of these failures occurred during initial characterizations.**
- **For three successive Scorecards, PVEL has highlighted junction box failures as an increasingly common, yet preventable issue.**
- **9% of BOMs experienced failures during the mechanical stress sequence, more than in any other test. The majority of failures were identified in visual inspection, revealing damaged modules and dislodged junction box lids.**




***Initial failures are those that were detected during intake characterizations prior to testing.***

## Spotlight on Junction Box Failures

High junction box failure rates in the PQP are particularly concerning because most failures occurred out-of-the-box before testing. This suggests junction box quality and construction are frequently overlooked during the manufacturing process. Junction box failures included poor sealing of the junction box lid, wet leakage failures originating at the junction box adhesive or pottant, and junction box bypass diode failures.

A possible cause of increased failures is that some junction box production steps are difficult to automate. Junction boxes are usually installed and sealed manually, even in state-of-the-art factories where other processes are automated. Further, before 2018 one junction box per module was typically installed. Most modern modules contain three junction boxes to accommodate the electrical properties of half cut cells, and precise placement is required so as not to shade cells. Imprecise handiwork in this process can result in defects.

## Types of Failure

### Safety

Modules with safety failures may be hazardous to operate in the field. Safe operation is determined via wet leakage testing using the IEC 61215 standard, which evaluates the electrical insulation of the PV module.

### Visual inspection

Visual inspections identify major manufacturing defects that cause premature field failure. Modules are examined for delamination, corrosion, broken or cracked surfaces and other changes to the module using the IEC 61215 criteria.

### Power degradation

Modules with power degradation failures may underperform in the field and ultimately result in financial losses for the asset owner. Although the PQP does not assign specific pass/fail thresholds for degradation, manufacturers may remove products from testing if rates fall below expectations. They typically change BOMs or production processes, then submit new samples for retesting. Retests are clearly noted in PQP reports.

### Electroluminescence

Modules undergo EL imaging throughout the PQP test sequences. No pass/fail thresholds are applied to EL images, but manufacturers may discontinue testing if the level of cell damage observed is higher than anticipated. In these cases, PVEL records an EL failure and a new sample may be submitted for retesting.

***Junction box failure in the field. Photo courtesy of Photovoltaik Buero.***

# Historical Scorecard

The Historical Scorecard shows Top Performers and their performance history since PVEL's first Scorecard published in 2014. Manufacturers are listed by the number of years they have been designated a Top Performer, in alphabetical order. PVEL commends manufacturers committed to product quality and reliability who have earned Top Performers status.

| | 2021 | 2020 | 2019 | 2018 | 2017 | 2016 | 2014 |
|---|---|---|---|---|---|---|---|
| Jinko | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Trina Solar | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| JA Solar | ■ | ■ | ■ | ■ | | ■ | ■ |
| Q CELLS | ■ | ■ | ■ | ■ | ■ | ■ | |
| REC Group | ■ | ■ | ■ | ■ | ■ | ■ | |
| Astronergy | ■ | ■ | | ■ | ■ | | ■ |
| GCL | ■ | ■ | ■ | ■ | ■ | | |
| LONGi | ■ | ■ | ■ | ■ | ■ | | |
| Adani/Mundra | ■ | ■ | ■ | ■ | | | |
| Maxeon/SunPower | ■ | ■ | | ■ | ■ | | |
| Phono Solar | ■ | | ■ | ■ | | ■ | |
| Seraphim | ■ | ■ | ■ | | ■ | | |
| Silfab | ■ | ■ | ■ | | ■ | | |
| Vikram Solar | ■ | ■ | ■ | | ■ | | |
| Boviet | ■ | ■ | ■ | | | | |
| First Solar | ■ | ■ | | ■ | | | |
| HT-SAAE | ■ | ■ | | ■ | | | |
| Hyundai | ■ | | | | ■ | | |
| LG Electronics | ■ | | | ■ | | | |
| Talesun | ■ | | | | ■ | | |
| DMEGC | ■ | | | | | | |
| ET Solar | ■ | | | | | | |
| HHDC | ■ | | | | | | |
| Jolywood | ■ | | | | | | |
| Risen Energy | ■ | | | | | | |
| VSUN | ■ | | | | | | |

# Why Testing Matters

### Limits of Warranties and Certifications

Certifications and warranties are important prerequisites for global market acceptance and financing of solar PV technologies. However, certifications do not ensure PV module reliability and warranties do not provide full protection for asset owners when failures occur in the field.

## Industry Perspective: PVEL's Data De-risks Investments

***"As PV manufacturing capacity expands, mega-scale, 100+ MW projects financed by risk-averse traditional investors are the new norm. Yet the most innovative technologies are unproven in the field. We trust PVEL for the technical data we need to de-risk Primergy's 2GW project pipeline."***

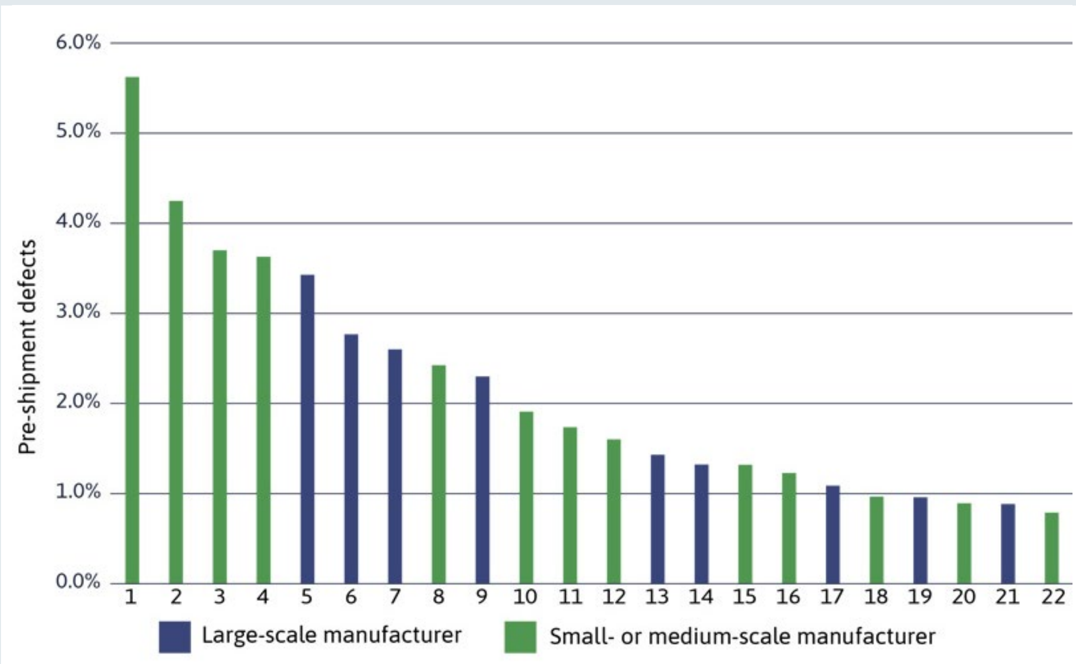
**Adam Larner, Chief Operating Officer of Primergy Solar, a wholly owned subsidiary of Quinbrook Infrastructure Partners, a global investment manager with $8B invested in 19GW of power generation.**

# Industry Perspective: Defects in the Factory

## Pre-shipment Defects vs. Manufacturer Size

Even certified modules can contain both overt and latent defects which are not easy to detect once modules leave the factory. The results of regular in-factory inspections conducted by PI Berlin show that defect rates in new build modules remain variable and range from less than 1% to over 5% depending on the specific manufacturer.

The results also demonstrate that higher quality is not always associated with larger manufacturers, which are those that accounted for > 75% of PV module shipment volumes in 2020.




*The rate of major defects by manufacturer is shown here. Major defects are defined as those which have the potential to impact module performance and reliability.*

*The industry's largest manufacturers are represented in blue. They are defined as those that collectively accounted for >75% of 2020 shipment volumes.*

The data in the chart above represents major defect rates by manufacturer and is based upon the results of recent pre-shipment inspections on over 84,000 modules sampled from production of more than 6 GW produced for major projects in the U.S. To be counted in this dataset, the defect must have been missed during the manufacturer's final flash, EL or visual inspection.

The most common defects are related to the cells and cell circuit, including the cell inter-connects and layout. These defective modules are identified and screened out by third-party inspections, but in cases where no third-party inspection is conducted, these defective modules could be shipped to a field site.

Although third-party inspections and oversight have become more common in the past few years, constant changes in technology, materials and manufacturing processes mean that maintaining consistent quality remains an ongoing challenge.

**Contributed by:**
**Ian Gregory, Managing Director,**
**PI Berlin North America**

BERLIN PI Trusted Solar Advisors

# Industry Perspective: Defects in the Field

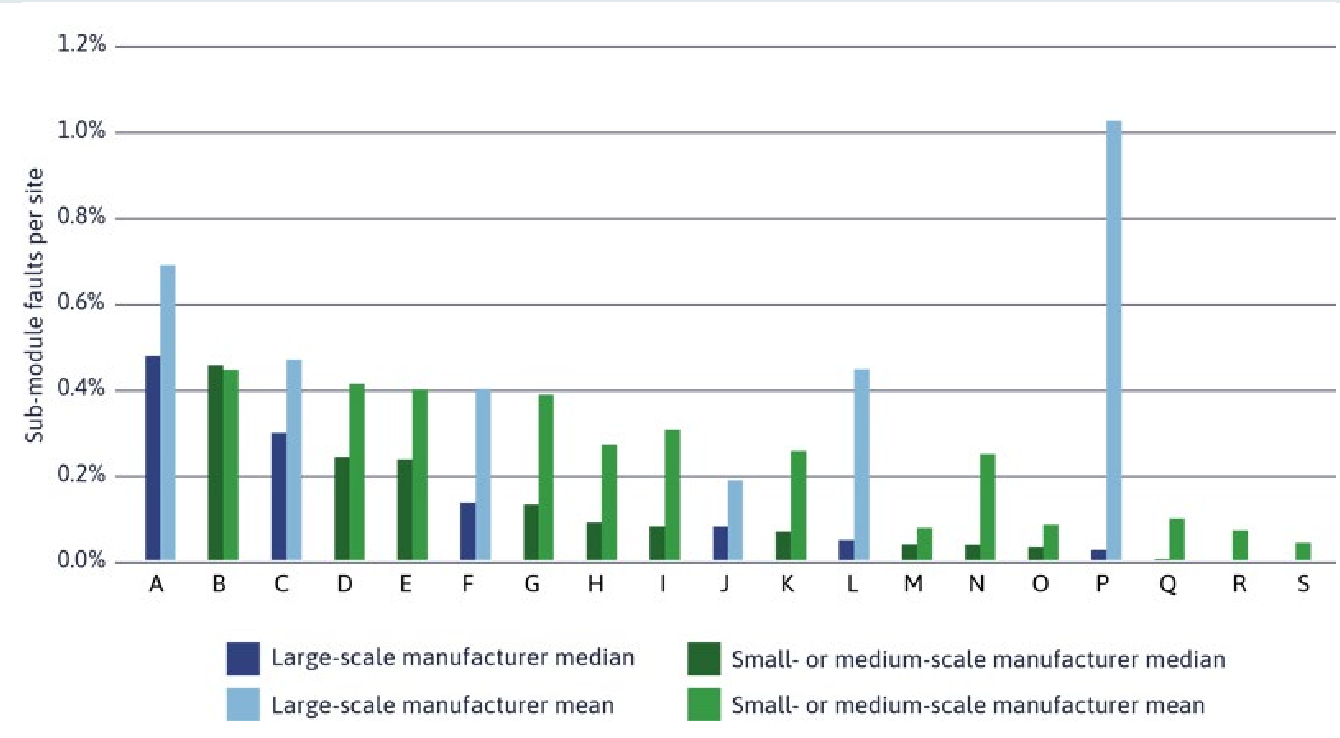
## Field Reliability vs. Manufacturer Size

Heliolytics has aerial-infrared scanned 3,600 operating PV systems globally, representing over 39 GW. Aerial infrared scans identify defects in PV modules that cannot be seen by visual inspection.

**Analysis of this data reveals that manufacturer size does not correlate with field reliability.**

The chart below shows mean and median sub-module failure rates per site by module manufacturer. These are failures with at least one third of the module in short circuit, leading to at least a 33% drop in module power. They are a good indicator of major reliability issues caused by poor soldering, diode failures, backsheet and/or cell reliability issues.

The mean value for submodule faults per site provides a good representation of portfolio performance. The median value is more reflective of a single site. The submodule fault results for the top ten largest manufacturers by 2020 shipping volume are interspersed across the graph.  This data indicates that the size of a manufacturer is not a consistent indicator of reliability or quality.




*This analysis is restricted to manufacturers for which Heliolytics has scanned at least 200,000 modules or 20 sites. The 10 largest manufacturers by 2020 shipment volume are segmented.*

***Product quality needs to be well-controlled as manufacturers expand production capacity.***

Contributed by:
Rob Andrews,
CEO, Heliolytics

# Conclusion

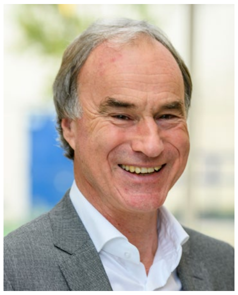
As the reality of climate change spurs nations and companies toward aggressive clean energy targets, the expansion of solar power must continue. But rapid growth it is not without risk. As PV module manufacturing capacity increases, so do mistakes on production lines.

Technical advances are raising expectations for energy yield in the field. These expectations cannot be fulfilled if manufacturers overlook quality controls and buyers do not require these controls. The high failure rates noted in this year's Scorecard, particularly for junction boxes – a basic component that is fundamental to safety – prove that independent testing remains necessary.

PVEL is expanding alongside the industry. Continuing on our decade+ mission to deliver empirical data that drives the adoption of reliable solar power, PVEL has partnered with Kiwa, a global testing, inspection and certification firm, to make our data matter for every solar power plant on every continent.

"At Kiwa we are very proud of our new partnership with PVEL, not only because of the synergistic effect this cooperation offers our customers as demand for solar power grows, but also because PVEL's North American presence brings Kiwa close to our customers on all continents – just as Kiwa's global footprint brings PVEL closer to its partners around the world.

Since our founding in The Netherlands in 1948, Kiwa has become an international quality service organization that supports companies as they improve their products, services, processes and even their teams – which is vital as industries grow and markets evolve. Together with PVEL, we are increasing our contributions to the advancement of solar power, and toward a better, more sustainable world."



**PAUL HESSELINK**
CEO,
KIWA GROUP

# Next Steps

**As a member of the Kiwa Group, PVEL is positioned to meet accelerating demand for independent testing especially as PV module technology radically changes.**

PVEL is actively testing many products that represent the most anticipated and debated technical advancement today: large-format PV modules. Some manufacturers and designs currently under test are detailed in the table below.

**Large Format Modules under Test**

| MANUFACTURER | PRODUCT DESIGN |
|---|---|
| Astronergy | 182mm, 144-cell, bifacial;<br>210mm, 132-cell, bifacial |
| Boviet | 182mm, 144-cell, bifacial |
| DMEGC | 182mm, 144-cell, bifacial |
| ET Solar | 182mm, 144-cell, bifacial |
| HT-SAAE | 182mm, 144-cell, bifacial |
| Jinko | 182mm, 144-cell, bifacial |
| Maxeon/SunPower | 210mm, shingled, bifacial |
| Risen Energy | 210mm, 110-cell, bifacial |
| Seraphim | 182mm, 144-cell, bifacial |
| Trina Solar | 210mm, 120-cell, monofacial;<br>210mm, 110-cell, bifacial;<br>210mm, 110-cell, monofacial;<br>210mm, 132-cell, bifacial;<br>210mm, 132-cell, monofacial |
| VSUN | 182mm, 144-cell, bifacial |
| Suntech | 182mm, 144-cell, monofacial |

## Take Action

When manufacturers test with PVEL, they can provide the performance and reliability insights their customers need. Downstream solar energy companies rely on PVEL data to procure PV modules that meet performance expectations.

**Building high-quality solar plants must be our collective mission if we are to meet the challenges of climate change – today and in the future.**

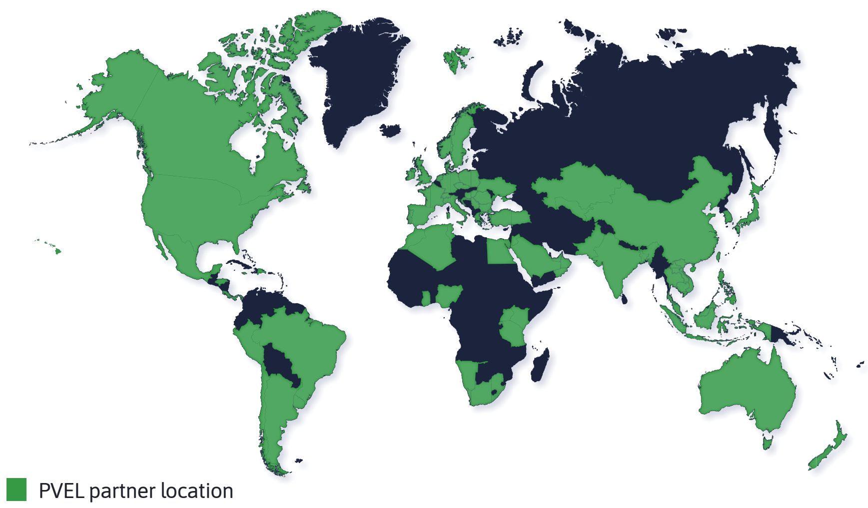
PV EVOLUTION LABS

# Interested in becoming a PVEL Downstream Partner?

Join our global network for complimentary access to our PQP reports for PV modules, inverters and energy storage systems.

**Learn more about our PQPs and sign up online at pvel.com**

**The PVEL Network**




**PVEL's downstream partners operate in solar and energy storage markets around the world.**