PV MODULE TESTING

Certifications Only Address Product Safety

Most solar project developers and equipment buyers require two key certifications for solar PV modules – IEC 61215 and IEC 61730 or UL 1703. They demonstrate that PV modules are safe. **None of these test standards address long-term PV module reliability and performance in the field.**

- IEC 61730 and UL 1703 only certify that PV modules are not hazardous to operate.
- IEC 61215 only screens for defects that would appear in the first few years of operation.
- Manufacturers select the specific modules that are used in certification tests. It is possible to send "golden samples" that are constructed more carefully than commercially produced modules.
- Manufacturers can change some component combinations of their module BOM without re-certifying the module model.

Additionally, updating IEC and UL standards is a multi-year process that cannot keep pace with the rate of innovation in solar PV module technology. **Both standards fail to identify major field performance issues associated with technical advances,** such as Light and elevated Temperature Induced Degradation (LeTID) and Potential-induced Degradation (PID). An LeTID test will be included in the next version of the PVEL PQP, which will be released in summer 2019.

Testing for Reliability and Performance

While IEC and UL certifications are important indicators of module safety, long-term reliability and performance are also important to PV buyers. Since its founding in 2010, PVEL has consulted with developers and financial institutions to continually develop test programs that address specific issues observed in the field and with emerging and even proven technologies.

By extending IEC 61215 sequences and incorporating additional tests, PVEL's PQP approximates the impact that decades of exposure in the field has on PV modules.

Extended reliability testing at PVEL's Berkeley Lab

What are the limitations of PV module warranties?

Nameplate and Solvency

Some module power degradation is expected, so a degradation factor is usually built into solar assets' energy yield and financial models as well as manufacturers' warranty terms. Warranties typically guarantee approximately 97% of the nameplate rating during the first year followed by an annual 0.6 to 0.7% reduction in the subsequent 24 years. **However, warranties only protect buyers when manufacturers are solvent and responsive to claims.**

Imprecise Measurement

Measuring power degradation that could be a warranty claim is extremely difficult – if not impossible – in the field. Measurement tools and sensors simply lack sufficient precision. A 3% allowance for uncertainty is usually applied for warranty enforcement, which effectively reduces guaranteed power output by 3%. Most successful warranty claims are therefore limited to excessive underperformance or total failure.

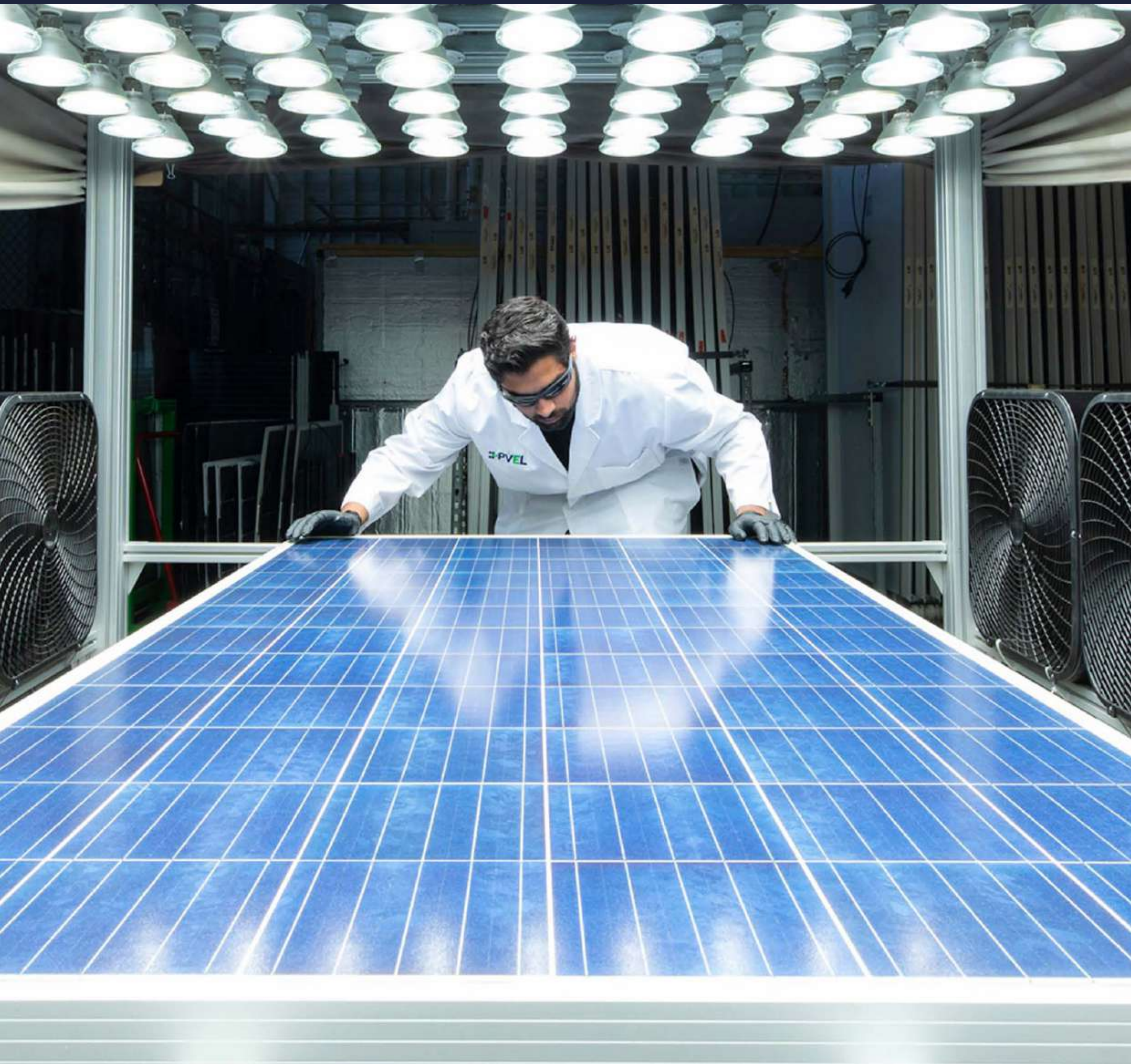
Coverage Limitations

Even when claims are accepted, most warranties only cover the cost of replacement modules, not costs associated with labor or lost energy production. Advances in the manufacturing process can also jeopardize future module replacement. For example, the product roadmaps of many major manufacturers today call for increasing wafer size and thus module size. This will result in modules that are not compatible with the modules they sell today. **Asset owners may be unable to replace defective modules in operating systems, which makes procuring reliable PV modules even more important.**

Certifications and warranties cannot fully protect PV module buyers from field failures and subsequent financial consequences.

PART 3

TEST RESULTS



PV MODULE PQP METHODOLOGY

PVEL launched the PV Module Product Qualification Program (PQP) in 2012 with two goals:

1. To provide PV equipment buyers and power plant investors with independent, consistent reliability and performance data that supports effective supplier management.
2. To independently recognize manufacturers who outpace their competitors in product quality and durability.

Today the PVEL PQP is a common requirement for PV modules installed in systems around the world.

PQP Test Development

Throughout the year and on a global scale, PVEL investigates field failures and monitors developments in the PV standards community. We work with research institutes, conduct experiments, and receive feedback from the upstream module manufacturers and downstream module purchasers (i.e. EPCs, developers, investors and insurance companies).

These inputs guide annual updates to the PQP and ensure that PVEL's reports deliver the data that equipment buyers need.

The Key Principles of the PVEL PQP

Empirical data
The PQP replaces performance assumptions with empirical metrics that help PVEL's Downstream Partners optimize revenue and energy yield models. Each PVEL PQP provides nine detailed test reports that PVEL's partners freely access to support their purchasing decisions.

No hand-picked samples
All Bills of Materials (BOMs) of products submitted to PQP testing are witnessed in production - from opening of raw materials packages through every step of the production process - to wrapping the completed pallet in tamper-proof tape.

Standardized processes
All BOMs are tested in the same way, using consistently calibrated equipment and in consistent laboratory environments. This enables a leveled comparison across all manufacturers.

Updated regularly
The rapid pace of technology development requires a test program that stays current in order to properly assess and qualify new products. PVEL updates the PQP annually to provide buyers with consistently relevant data to evaluate PV products.

What is a factory witness?

Years of PQP test results demonstrate that the module's Bill of Materials (BOM) is one of the key quality drivers. To verify the specific BOM combination used in module production, PVEL's auditors follow a 5-step factory witness process:

1. Photograph BOM components as materials are removed from their original packaging
2. Observe and record over 100 technical details about the BOM
3. Strictly track each BOM component through every step of production and packaging
4. Document recipes used for soldering and laminating
5. Conduct a high-level process audit of the factory

Using exhibits to specify BOMs in their contracts helps PV module buyers ensure that they receive products with the exact components that achieved satisfactory PQP test results. **PVEL provides Downstream Partners with detailed BOM listings in exhibits for inclusion in module supply agreements.**

Interested in becoming a PVEL Downstream Partner?

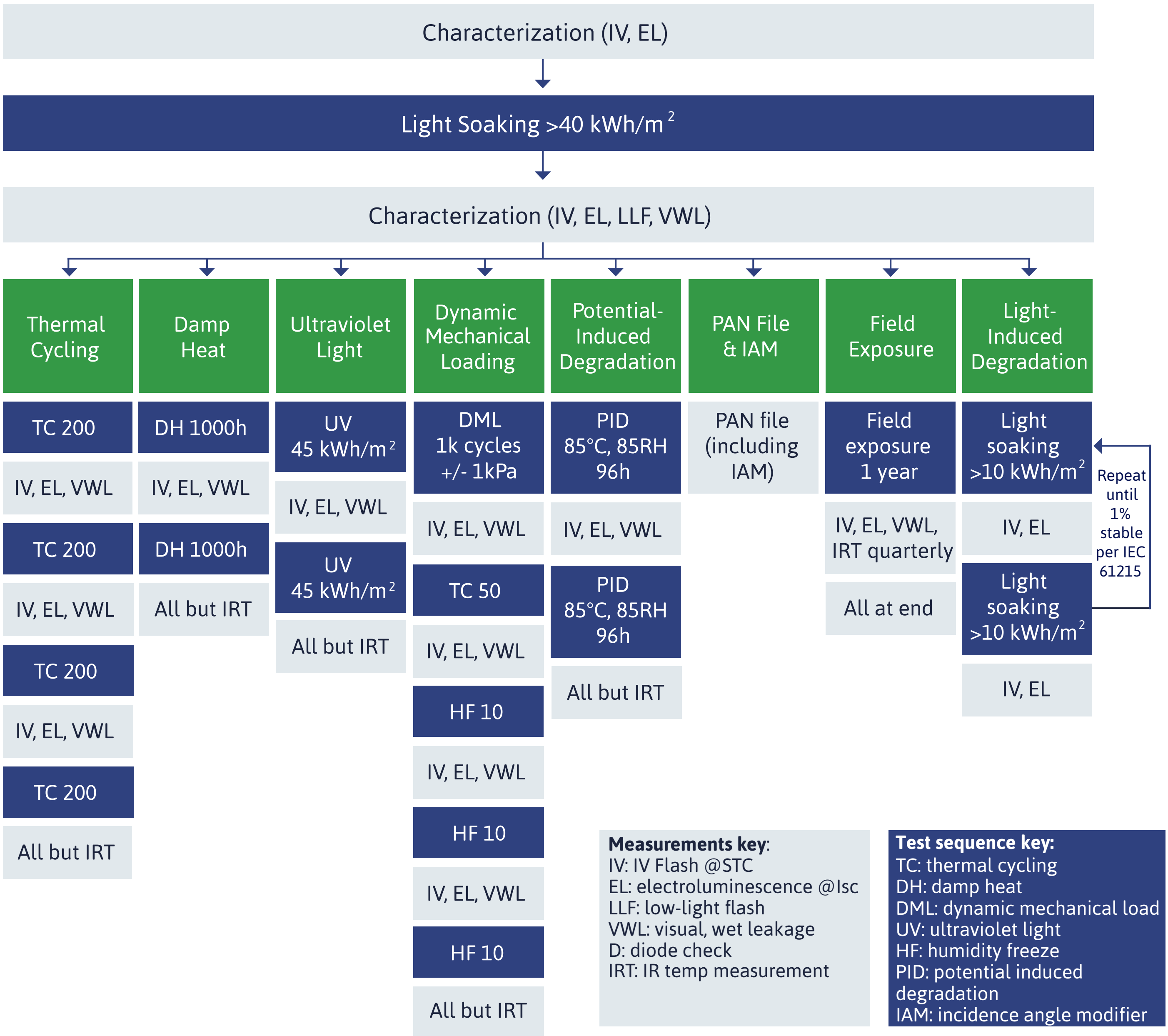
Learn more about our PQPs and sign up online at:

pvel.com/PQPs

"As an early champion of rigorous technical due diligence, we know first-hand that mitigating risk through strategic procurement is a much sounder strategy than relying on warranties alone. PVEL's Product Qualification Program is designed to help developers invest confidently in new technologies that promise greater returns, particularly when long-term field performance data is unavailable."

ABHIJEET SATHE, Chief Operating Officer, SB Energy, a division of Softbank

2018 PVEL PRODUCT QUALIFICATION PROGRAM



RESULTS OVERVIEW

Methodology

The PQP results presented in the 2019 Scorecard were factory witnessed within 18 months of 2019. Results presented in the bar charts on the subsequent pages show average values for the different test samples and BOMs which together represent a single module model. Each test sequence had a varying number of manufacturers and model types participating.

The Top Performers in each test category are listed in alphabetical order. Top Performers are model types that degraded less than 2% for the entirety of the test sequence.

Reading the Results

Each test sequence is detailed over two pages and includes:

1. An overview of the stress testing and real-world context of the specific failure mechanism
2. An example of high levels of degradation, including electroluminescence (EL) images and electrical parameters
3. The 2019 results graphically presented showing the average power loss by model type
4. An alphabetical list of Top Performers
5. A results summary for that specific test

PVEL cautions that not all products/model types are represented in every test. For example, some model types are not subjected to all tests, or some results may not have been available at the time of publication. Buyers should contact PVEL to obtain the full reports that comprise these results. The full reports contain BOM-level results whereas the results herein are reported at the model level.

Results Summary

New for this Scorecard edition is the inclusion of PVEL's historical data from nearly ten years of testing. The bar charts that follow indicate how the 2019 Scorecard results compare to PVEL's historical dataset.

The presented data indicates a general trend of improved performance in thermal cycling and potential-induced degradation; however, a wider range of performance can be observed for damp heat and the dynamic mechanical load sequence.

PQP participants tend to place a higher value on the quality of their products than non-participants. As such, the median results may be better than those of the broader industry, especially for modules one might source on the open market. See Procurement Best Practices on page 30 for PVEL's module purchasing recommendations.

> "Earning PVEL's Top Performer designation helped us grow U.S. market share at a pivotal moment in Jinko Solar's international expansion. Since then, we have leveraged PVEL's Product Qualification Program to prove the reliability and performance of our most advanced products to prospective buyers in markets around the world.
>
> **DANIEL CHANG,** Technical Director - North America, Jinko Solar

THERMAL CYCLING: OVERVIEW AND RESULTS

Background

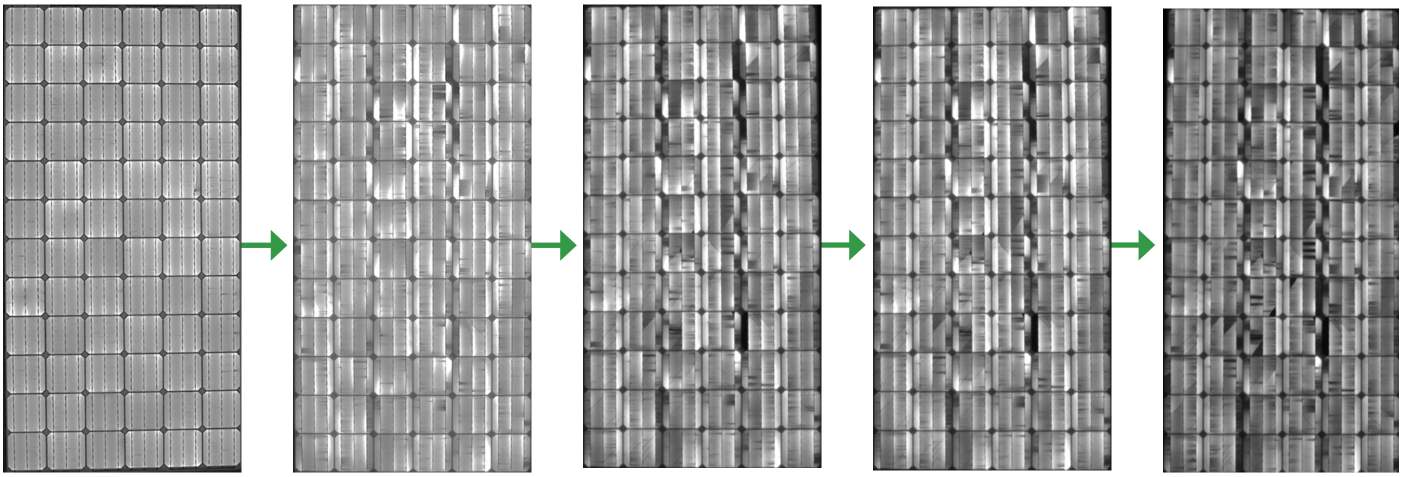
PV module components expand and contract in response to changes in temperature. Because these components have different thermal expansion coefficients, they change size at different rates in the same environmental conditions. This creates interfacial stress, a thermodynamic effect that reduces the strength of the bonds between each layer of the PV module. One example is solder bond fatigue, which increases series resistance and decreases module performance at high irradiance.

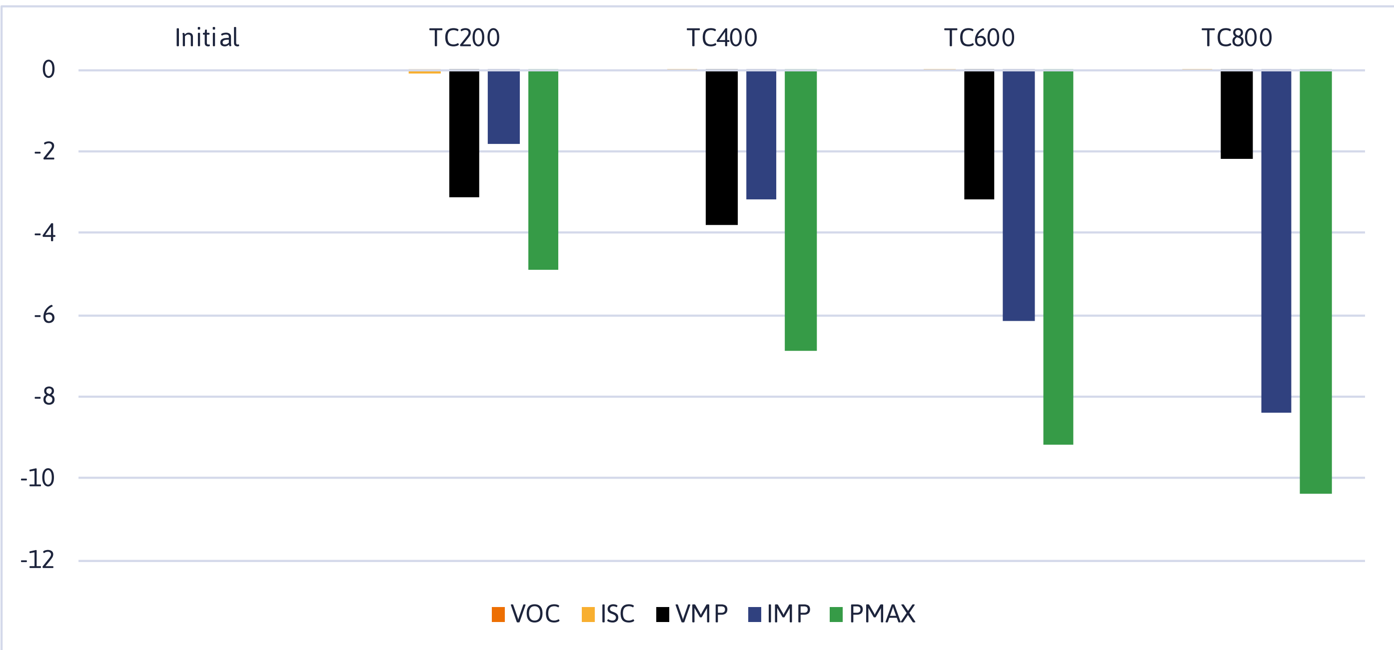
Why the Test Matters

The material components of PV modules will expand and contract many times over 25+ years in the field, even in temperate climates. With module operating temperatures well above ambient, this effect occurs daily and can be extreme in deserts and other arid environments. This test demonstrates if the temperature cycles are likely to cause undue interfacial stress that decreases performance.

Thermal Cycling Procedure

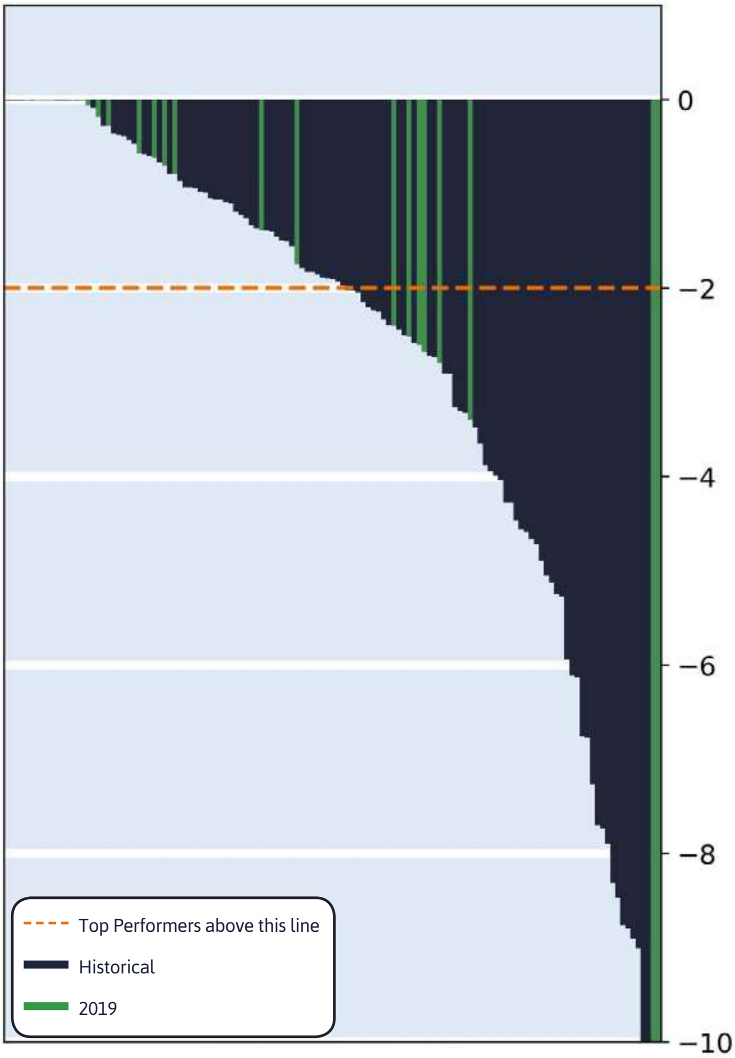
Modules are placed in an environmental chamber where the temperature is lowered to -40°C, dwelled, then increased to 85°C and dwelled again. Maximum power current is applied to the modules while the temperature is increased and decreased. This is repeated 800 times for PVEL's PQP. One cycle takes about three hours to complete. IEC 61215 testing requires only 200 cycles.





2019 TOP PERFORMERS	
Manufacturer	**Module Model**
Boviet	BVM6612M-xxx-H / BVM6610M-xxx-H
GCL	GCL-M6/72Hxxx / GCL-M6/60Hxxx GCL-P6/72Hxxx / GCL-P6/60Hxxx
Hanwha Q CELLS	Q.PEAK DUO L-G5.2 xxx Q.PEAK DUO-G5 xxx
JA Solar	JAM60S02-xxx/PR JAP72S01-xxx/SC / JAP60S01-xxx/SC
Jinko	JKMxxxM-60B JKMxxxM-72 / JKMxxxM-72-V / JKMxxxM-60 / JKMxxxM-60-V
LONGi	LR6-72PH-xxxM / LR6-60PB-xxxM
REC Solar	RECxxxTP2M RECxxxTP2
Silfab	SLGxxxM / SLAxxxM
Trina Solar	TSM-xxxPE14H / TSM-xxxPE05H TSM-xxxDE14H(II) / TSM-xxxDE05H(II)

Power Degradation for Each Module Model



Results in Context: Key Takeaways

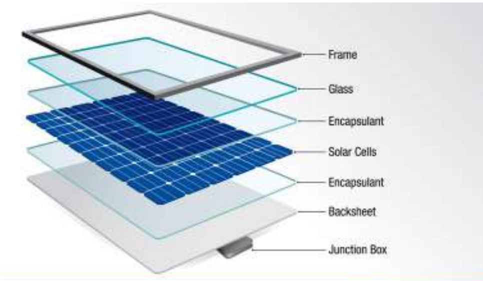
The 2017 and 2018 Scorecards presented thermal cycling data from past PQPs where the sequence duration was 600 cycles. Therefore a third of the historical data (in blue) terminates at 600 cycles. The 2019 data (in green) represents 800 cycles. Despite this 25% increase in test duration, performance clearly improved. Two notable exceptions include high degradation data points, which are discussed in relation to diode failures on page 26.

The EL images show a module that barely passed the IEC 61215 TC threshold with less than 5% degradation after TC200. Additional thermal cycling revealed increased failures in solder bonds between cells and interconnecting ribbons. This demonstrates the absolute importance of proper materials selection, process quality control, and extended stress testing.

DAMP HEAT: OVERVIEW AND RESULTS

Background

PV modules are constructed of different components that are laminated together. These layers must remain firmly adhered for the PV module to meet performance expectations. Moisture and high temperature can degrade the adhesives that bond these layers together, allowing water, dirt, soil and other materials to enter the module and degrade its internal components, thus reducing energy yield. Delamination may also decrease the insulation resistance of a PV module, which makes electrical shock more likely.



Why the Test Matters

High temperature and high humidity are common in many tropical and subtropical parts of the world. PV modules in moderate climates also experience periods of high temperature and humidity. These exposures can cause premature failures and degradation when poor quality components or improper lamination procedures are used. PVEL's damp heat test reproduces degradation and failure modes that occur in the field.

Damp Heat Procedure

Modules are placed in an environmental chamber and held at a constant temperature of 85°C and 85% relative humidity for 2,000 hours (about 84 days). The heat and moisture ingress stress the layers of the PV module. IEC testing has a duration of only 1,000 hours.