RETC

PV MODULE INDEX REPORT

2020

Contents

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About RETC

RETC, LLC is a leading engineering services and certification testing provider for renewable energy products headquartered in Fremont, CA.

RETC puts customers at the forefront while bringing value at all stages—from research and development, market entry, to bankability. Since its founding in 2009, manufacturers, developers, and investors have partnered with RETC to test products from a broad range of module, inverter, storage, and racking manufacturers. Only the latest testing standards and industry-accepted methods of vetting products are used in RETC labs. RETC is united by the belief that our work is enabling a safer and more sustainable future.

A letter from our CEO

CHERIF KEDIR

A solar industry veteran of over fifteen years spanning R&D, manufacturing, reliability, field testing, certification, and bankability with an extensive 13-year background in semiconductors.

The *PV Module Index Report (PVMI)* was created last year in response to a need in the market for a completely comprehensive summary of the PV module market's top players. Renewable Energy Test Center (RETC) has been the first of its kind to examine three indicative components that are summarized in a single report.

We have created and continued to improve our annual *PVMI* so that the findings we publish focus on the following:

- Extensively data-backed reports that collate performance, quality, and reliability
- Objectively examining manufacturers' accomplishments and highlighting the leaders
- A report that is free and accessible to everyone

In creating the *PVMI*, we avoided creating a report that ultimately ranked manufacturers. Instead, we focused on specific products and product families. We created our *PVMI* report to be as direct as possible. High-achieving manufacturers selected by RETC succeed in all three *PVMI* indicators: reliability, quality, and performance.

We hope this is a useful tool for downstream partners for differentiating PV module manufacturers, and for upstream partners who continue to innovate and manufacture great products.

Cherif Kedir

Cherif Kedir
Chief Executive Officer
RETC, LLC

Categories for High Achievement

RETC compiles its annual *PVMI* report as a means of showcasing industry-leading PV module companies and technologies.

Our goal in consolidating and sharing these test data is to recognize high performers and showcase high achievement in manufacturing. To do so, we share relevant performance distribution data for individual indicators within each category or discipline, as well as best practices regarding testing and manufacturing.

As was the case last year, the bulk of the content in this report is broadly organized into three essential categories:

Manufacturers and product lines that achieve high performance according to these three disciplines not only demonstrate a commitment to excellence, but also provide a benchmark—a quantitative measure representing the best that the industry has to offer.

To characterize reliability, for example, we present performance distribution data based on accelerated testing and analysis of flat-plate PV modules. For the performance category, we present data characterizing module conversion efficiency and PVUSA Test Conditions (PTC) ratings. To characterize quality, we present results from the Thresher Test qualification protocols, which test beyond minimum requirements set forth in product safety standards.

RETC recorded all of the published data related to reliability, performance, and quality at its testing facilities during the 2019 calendar year. To contextualize these data, we provide information about relevant test methods, performance metrics, and best practices for quality assurance and control. Additionally, we consider some emerging industry trends and mine historical PV module listing data.

Industry Trends

Since RETC published its last *PVMI* report, our subject matter experts have observed some unmistakable industry trends, such as the increased adoption of bifacial PV modules and energy storage systems (ESS). We have discovered other interesting trends hiding in plain sight in the form of public data aggregated by the California Energy Commission (CEC). Most importantly, RETC observed an under-reported damp heat stress artifact, possibly related to boron-oxygen (BO) complex destabilization, the occurrence of which we are publicizing for the benefit of other industry stakeholders.

Damp Heat Stress Artifact

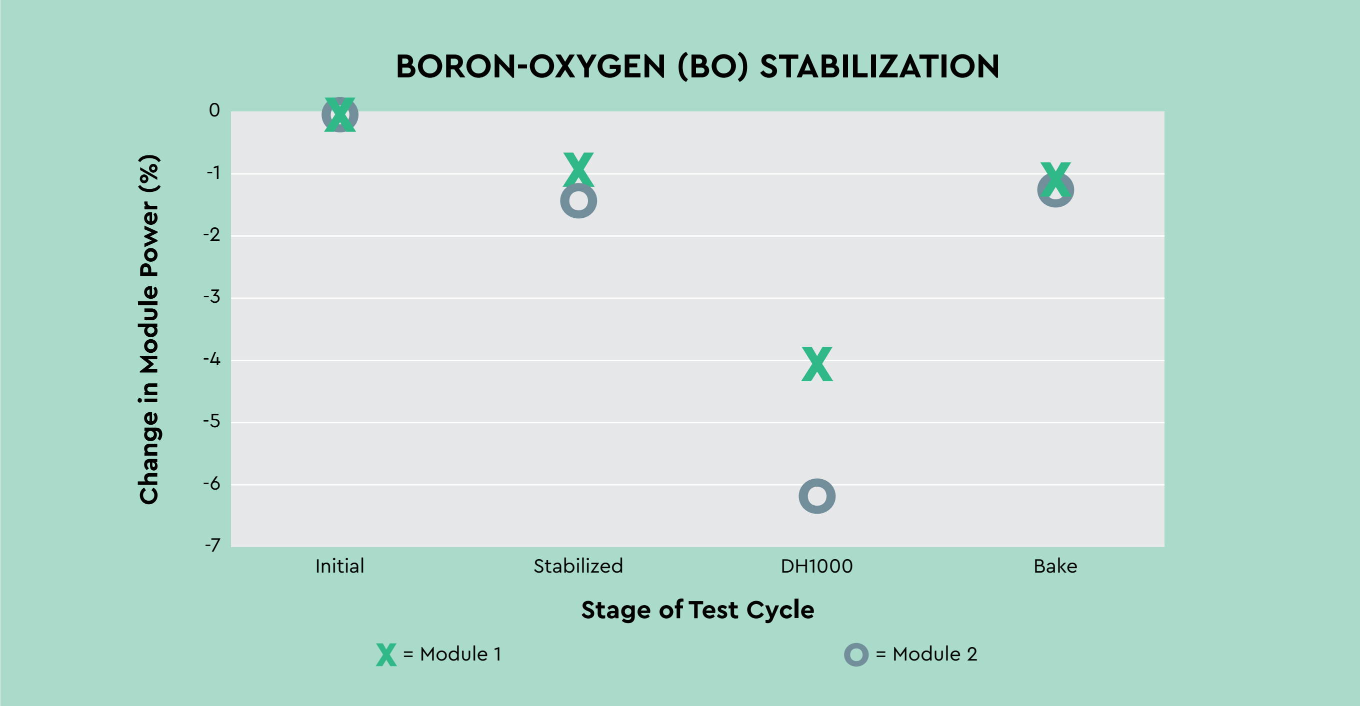
During its 2019 PV module testing activities, RETC observed an unusual performance destabilization effect in PV modules subjected to an accelerated 1,000-hour damp heat (DH1000) test sequence. Generally speaking, damp heat stress is an effective means of identifying certain early-life PV module failure modes. In this case, however, we observed that the power degradation effects resulting from the damp heat stress are reversible. This suggests that the effect is not likely to be representative of an early-life failure mechanism.

The data presented below illustrates the reversible nature of this damp heat stress artifact. Prior to the DH1000 test, stabilized module measurements indicate a typical change in module power of roughly -1%. After the DH1000 test sequence, module test measurements indicate a significant change in module power of -4% to -6%, respectively. Subjecting the samples to a baking process—involving a moderately elevated temperature and the application of light or current for one or two days—completely reverses the damp heat stress effect. This behavior is consistent with BO complex destabilization.

While BO destabilization is a well-known effect, it is only widely observed in recent products because of changes to module technology. Since BO complex occurs only when the sample module is hot, in the dark, and without current flow for many days, it is unlikely to be observed in fielded product. The effect reverses relatively quickly when current flows or illumination is present.

Due to the speed at which products with new technology have reached the market, there is little published data on this effect in commercial modules. Moreover, some manufacturers may fear any association with a type of performance decrease. Even if the decrease in power is reversible and occurs only under conditions not representative of product use, some might misinterpret this as a disadvantage.

RETC hopes that publicizing the occurrence of this behavior will allow industry stakeholders to modify test procedures appropriately and interpret test results in a meaningful manner. It would be a mistake to assign undue importance to a reversible heat stress artifact, especially one that is unlikely to be relevant to in-field PV module performance and durability.



CEC Data Mining

In order to qualify for California solar incentive programs, solar modules must be included on an eligible equipment list maintained and regularly updated by the CEC. This CEC listing requires additional testing and characterization beyond the basic UL product certification tests. Since California is a
major solar market and many other incentive programs follow its lead, CEC listing is a standard practice for many PV module manufacturers.

Note that the CEC does not accept self-reported data from manufacturers. Rather, CEC listing data are based on test reports from accredited third-party laboratories. Among these, RETC is one of the accredited laboratories most active in terms of testing modules for CEC listing.

The data used to calculate PVUSA Test Conditions (PTC) ratings are of particular interest to manufacturers. As compared to the standard test conditions (STC) ratings used to characterize module performance in factory setting, PTC ratings provide a better indication of in-field performance. Therefore, many solar programs use PTC ratings as the basis of financial incentive calculations.

Since a high PTC rating is desirable to manufacturers, it is helpful to understand how PTC ratings relate to other module parameters.

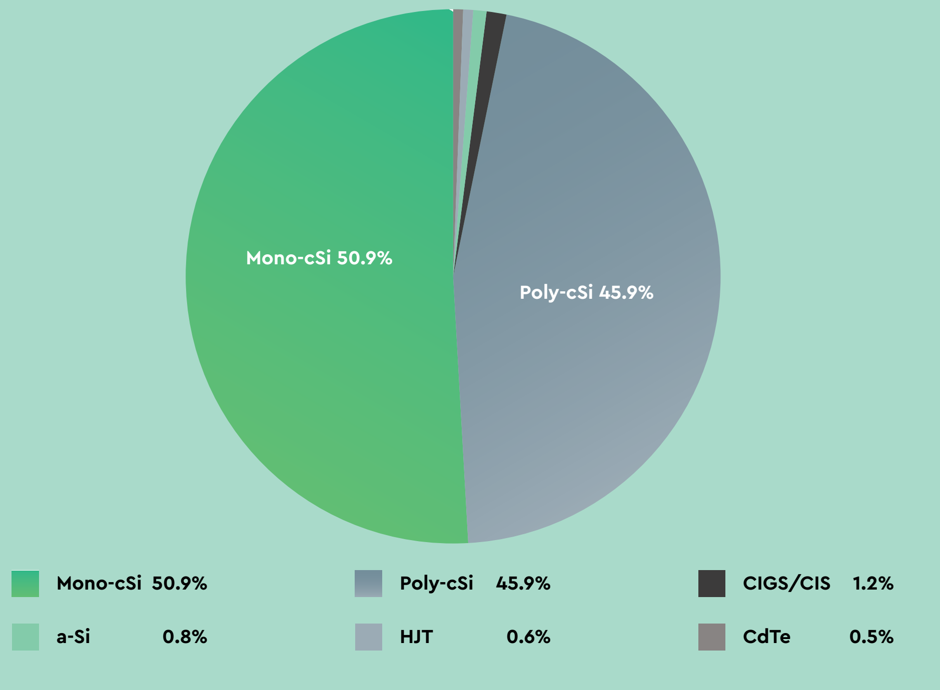
As illustrated on page 8, PTC rating is directly proportional to a module's temperature coefficient of power and inversely proportional to its nominal operating cell temperature (NOCT) and aperture area.

Over the course of many years, the CEC has accumulated data characterizing more than 25,000 PV modules from roughly 500 module manufacturers. That being the case, the CEC's database of PV module performance parameters is a rich data mining resource. As an example, here are some additional observations based on a review of the published CEC listing data from August 18, 2020:

- Manufacturers with BIPV modules = 31 (~6%)
- Manufacturers with half-cut cells = 30 (~6%)
- Manufacturers with bifacial modules = 25 (~5%)
- Manufacturers with heterojunction (HJT) PV = 7 (~1%)
- Largest flat-plate PV module aperture area = 5.72 m^2
- Highest efficiency (based on aperture area) = 22.8%
- Highest STC power capacity rating = 515 W

What follows here are some additional observations based on filtered CEC listing data. Note that we corrected some apparent typographical or categorizing errors in the source data. Apparent typographical errors show up as extreme data outliers, such as a temperature coefficient of power of -4.4%/°C which we corrected to -0.44%/°C.

CEC LISTING BY TECHNOLOGY



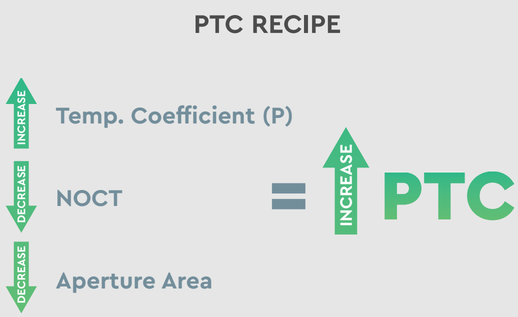
We also observed apparent categorizing errors—such as a module with polycrystalline (poly-cSi) cell type designation, on the one hand, and monocrystalline silicon (mono-cSi) product family designation, on the other—and regrouped data appropriately.

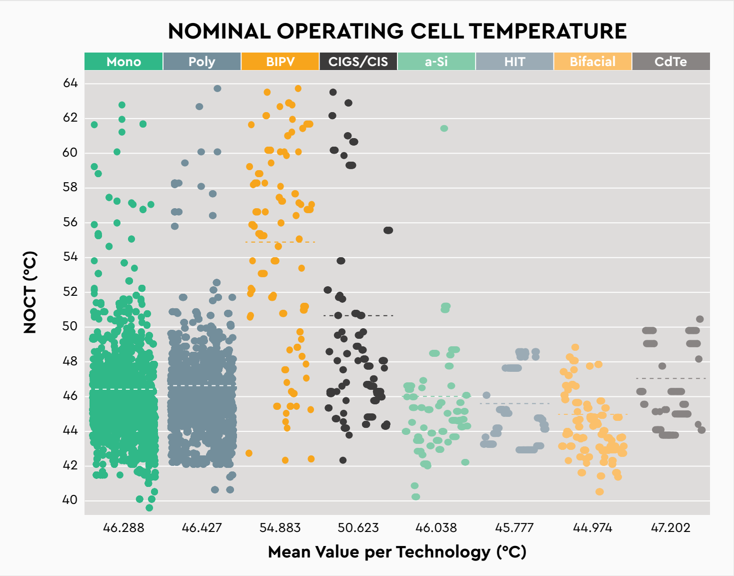
Cell Technology Sorting the data according to technology, we observe that more than 94% of the CEC-listed modules use some type of crystalline silicon cell, whereas less than 4% use some type of thin film technology.

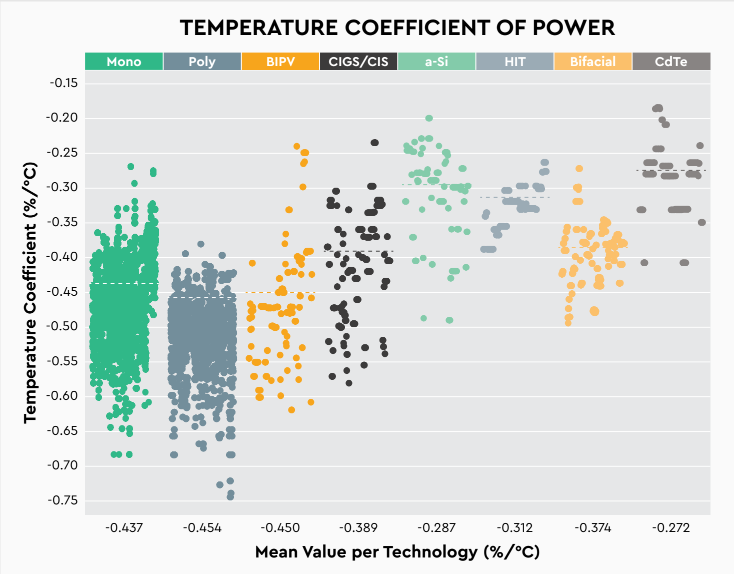
NOCT Filtering the data according to technology and plotting NOCT values, we observe that a mono-cSi module has the lowest value in the dataset at 40.6°C, which is more than 5°C lower than the overall average. It is also notable that the average NOCT for BIPV is roughly 10°C higher as compared to non-BIPV modules. This is not surprising given the fact that the back side of a BIPV module is poorly ventilated, resulting in elevated cell temperatures, due to its close proximity to the roof deck.

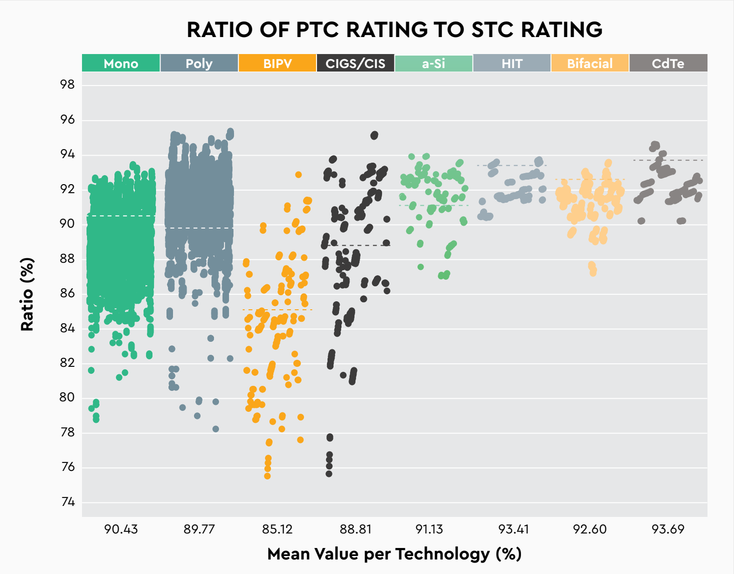
Temperature Coefficient of Power Filtering the data according to technology and plotting the temperature coefficient of maximum power values, we observe that a Cadmium Telluride (CdTe) thin film-type module has the highest value in the dataset at -0.1655%/°C, which is significantly higher than the category average of -0.44%/°C. As expected, the average temperature coefficient of power is better (higher) for thin film- and HIT-type modules as compared to mono- or poly-cSi technologies.

PTC-to-STC Ratio Filtering the data according to technology and plotting the ratio of a module's PTC rating as compared to its STC rating (PTC/STC), we observe that the average values are relatively high (93%) for amorphous-silicon (a-Si), CdTe thin film, and HJT, and relatively low (85%) for BIPV.







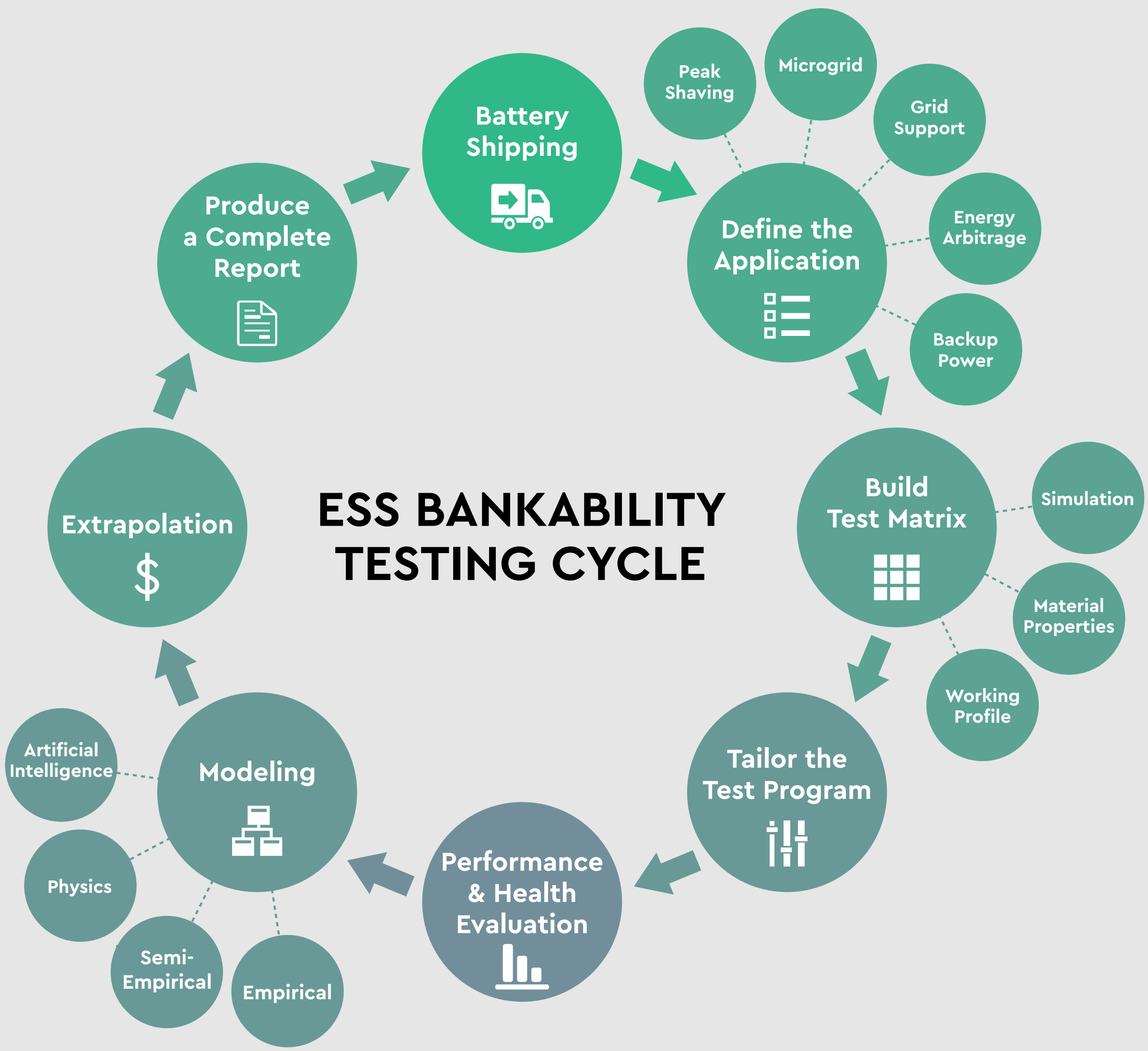


ESS Bankability Testing

The market for battery energy storage has grown from 30 MWh in 2014 to 16,000 MWh in 2020; the ESS market is expected to reach 35,000 MWh in the next three years. Due to this exponential growth, the need for standardized ESS testing programs is increasingly urgent. Without test standards to guarantee battery functionality, reliability, and safety over the life of the system, it will prove impossible to meet target goals—in California and around the globe—regarding universal access to clean and reliable electricity.

With that in mind, RETC is proud to introduce the industry's first comprehensive functionality, performance, and reliability test methodology for stationary ESS and electric vehicles (EVs). Paired with established standards and requirements for safety protocols, RETC's ESS test methodology—illustrated in the test cycle diagram below—represents the most comprehensive accelerated demonstrating ESS component bankability. Up until this point, downstream project developers, EPCs, IEs, and financial institutions had to rely on cell-level characterization tests and various UL and IEC protocols that focused on safety in order to characterize ESS risk profiles. With the introduction of RETC's ESS bankability program, stakeholders now have a way to characterize an ESS solution at the battery-module level.

Within a four- to six-month time period, stakeholders can understand performance in an intended use case, validate manufacturers performance claims, as well as develop a high-confidence predictive model on how the battery and ESS will perform and degrade over years of use. In addition to significantly mitigating risk, this test methodology will improve the accuracy of financial models—both of which are essential to wide-scale



Bifacial PV Certification

In June 2019, the Office of the US Trade Representative (USTR) added bifacial solar modules to a short list of solar products excluded from a general 30% tariff on imported solar cells and modules. Since that time, demand for bifacial PV testing and certification has surged. While the bifacial tariff exclusion remains unsettled in the courts, the general trend toward increased bifacial PV module manufacturing and testing is undeniable and likely unstoppable.

A recent techno-economic performance assessment estimates that bifacial solar modules fielded on single-axis trackers provide the lowest levelized cost of energy (LCOE) for 93.1% of the global land area. That being the case, bifacial solar modules are a preferred technology wherever PV assets are developed and deployed at scale.

The bifacial performance advantage stems from the fact that bifacial modules convert irradiance captured on both the front and back sides of PV cells into electrical power. By contract, monofacial PV technologies, which have been the norm in commercial solar applications for decades, convert only front-side captured irradiance into electrical power.

To properly assess and characterize bifacial PV modules, IEC's Technical Committee responsible for solar PV power systems has reviewed and revised three IEC standards.

The first of these is a two-part technical standard that describes procedures for measuring current-voltage (I-V) characteristics for bifacial PV devices. As described in an IEC abstract, IEC TS 60904-1-2:2019 is applicable to single PV cells, subassemblies of cells, or entire PV modules.

The standard allows for the use of natural or simulated sunlight to capture incident irradiance to both front and rear surfaces of the PV module via single- or double-side illumination. A primary goal of these tests is to characterize the PV modules' intrinsic bifaciality coefficients, which describe the ratio of the STC-rated back-side power as compared to the front-side power.

The second revised standard is IEC 61215, which describes design qualification test requirements and procedures for terrestrial PV modules. While the current edition of this standard dates to 2016, the Technical Committee has proposed a number of bifacial-specific revisions that are expected to be formalized in the next edition of the standard. Relevant changes include the addition of new bifacial terminology and test standards. For example, the bifacial nameplate irradiance (BNPI) protocol calls for a front-side irradiance of 1,000 W/m2 and a back-side irradiance of 135 W/m2. Relevant revisions will also standardize bifacial module marking and installation manual requirements.

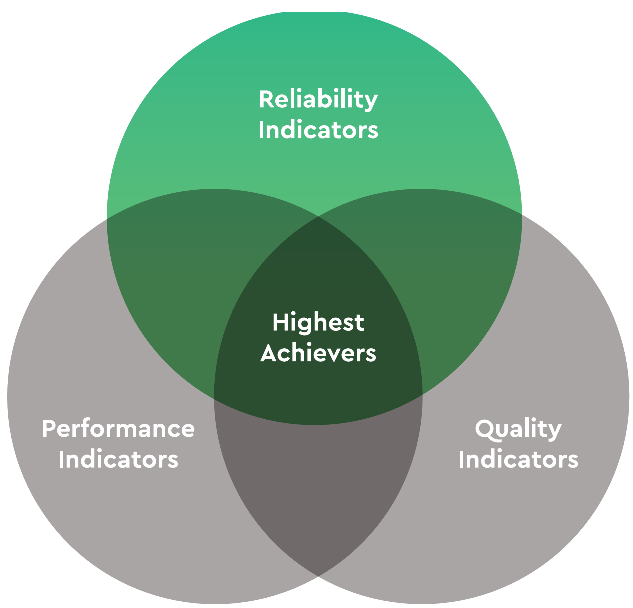
Last but not least, the Technical Committee has proposed bifacial-specific revisions to IEC 61730, the two-part standard pertaining to PV module safety qualification. Generally speaking, these proposed revisions mirror relevant changes found in IEC TS 60904 or proposed for IEC 61215. As with the design qualification standard, the current edition of IEC 61730 dates to 2016. Though the proposed revisions to the standard will not be formalized until the next edition, RETC is able to test and qualify bifacial products to these draft standards today.

Module Reliability

Product certification and qualification are essential first steps on the road to reliability. Accredited laboratories, such as RETC, play an important role in this process by offering certification testing to relevant Underwriters Laboratories (UL) and International Electrotechnical Commission (IEC) standards.

While product safety and design qualification are related, they are not identical. On the one hand, life and fire safety are the primary goals of the IEC 61730 standard. On the other hand, initial short-term product reliability is the primary goal of IEC 61215 standard. It is important to recognize that safety qualification and design qualification tests alone are not devised or intended to predict long-term reliability.

To characterize long-term in-field reliability, industry stakeholders—including subject matter experts at RETC—have developed enhanced testing standards, procedures, and sequences that go beyond minimum product safety and design qualification requirements. These beyond-qualification test protocols put additional stress on modules in order to identify areas of weakness and better predict long-term in-field reliability.



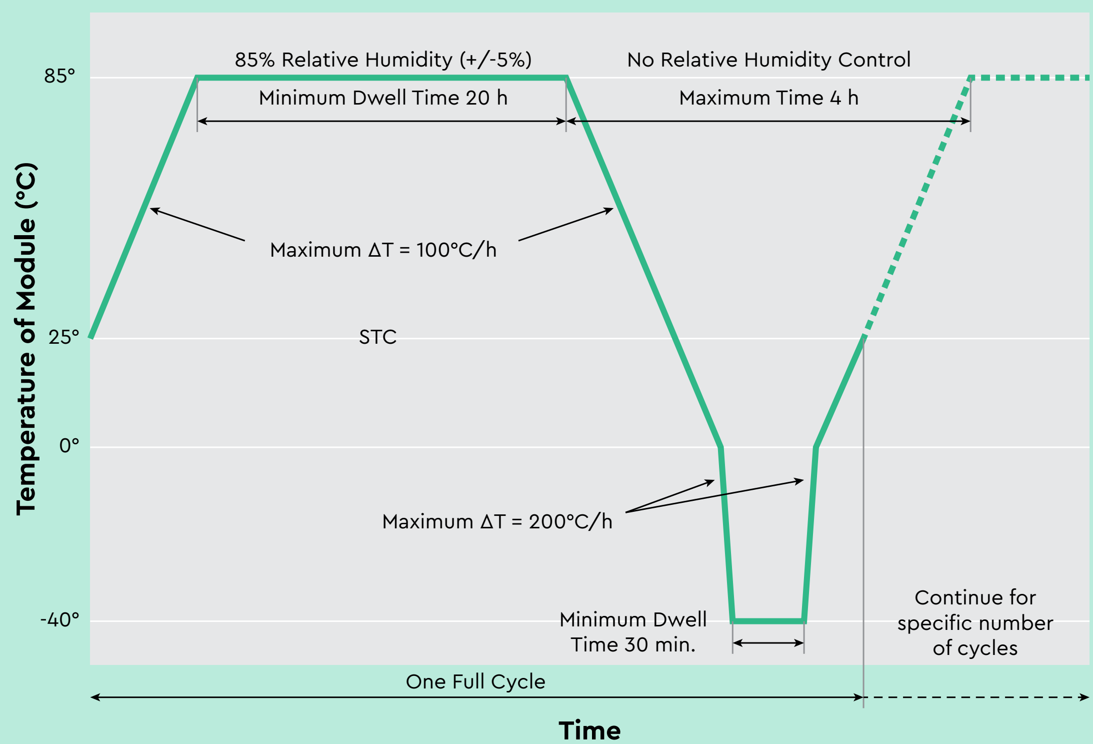
Reliability Tests & Metrics

A leader in the effort to develop accelerated reliability test protocols, RETC provides a variety of testing and characterization services to original equipment manufacturers (OEMs) and Nationally Recognized Testing Laboratories (NRTLs). Here, we provide a high-level overview of some flat-plate PV module tests that RETC conducts within its accelerated reliability testing program. Following the test descriptions, we provide a sampling of reliability test data that RETC compiled in 2019 and showcase OEMs according to high achievement in manufacturing.

Damp Heat (DH) DH testing characterizes a PV module's ability to withstand prolonged exposure to humid, high-temperature environmental conditions. This accelerated aging test takes place in an environmental chamber. Modules in the chamber are exposed to a controlled temperature of 85° Celsius and a relative humidity of 85% for a set amount of time. Typical Thresher or PQP testing includes a DH2000 test, indicating a duration of exposure of 2,000 hours—twice the duration of exposure typical required for product certification. The DH2000 test is an effective means of characterizing aging effects and potential failure modes associated with electrochemical corrosion, delamination, encapsulation adhesion and elasticity, junction box adhesion, and general deficiencies in edge deletion. (See p. 16 for module performance distribution data based on DH test results.)

Humidity Freeze (HF) HF testing characterizes a PV module's ability withstand the effects of heat and humidity followed by extremely cold environmental conditions. For this accelerated aging test, modules in an environmental chamber are exposed to a relative humidity of 85% and subjected to temperature cycling from 85°C to -40°C with no relative humidity control. Certification standards call for an HF10 test, allowing for no more than 5% degradation after the 10 cycles. Typical Thresher or PQP testing calls for subjecting modules to 30 or more humidity-freeze cycles. The HF30 test is an effective means of characterizing junction box adhesion rates, proper edge deletion, and delamination.

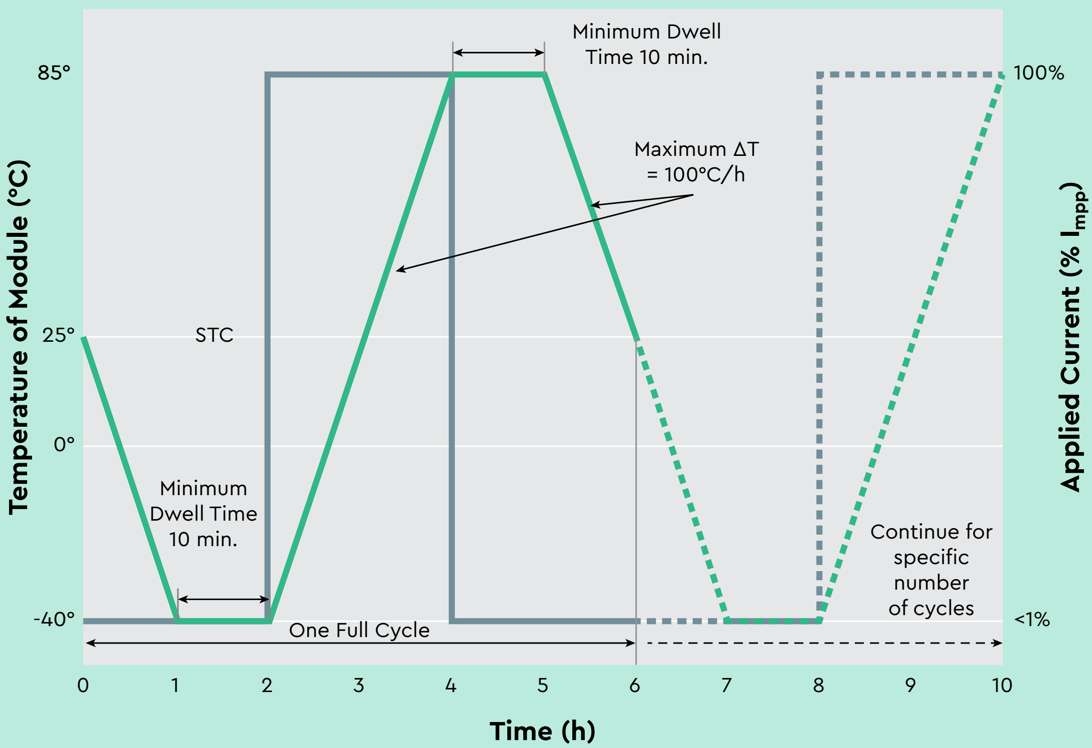
HUMIDITY FREEZE PROFILE



Source: IEC61215-2

Thermal Cycling (TC) TC testing is an environmental stress test used to assess product reliability and identify thermal fatigue failure modes. The TC test protocol consists of cycling modules in an environmental chamber between two temperature extremes—85°C on the high end and -40°C on the low end. Typical certification standards call for a TC200 test, consisting of 200 cycles. Extending the TC test through 600 or even 1,000 cycles is an increasingly common industry practice. Extended TC600 or TC1000 tests are an effective means of detecting weaknesses in module designs. Typical issues and failures modes identified via extended TC testing include broken interconnects, cracked cells, electrical bond failures, junction box adhesion deficiencies, and the potential for electrical arcs or open circuits.

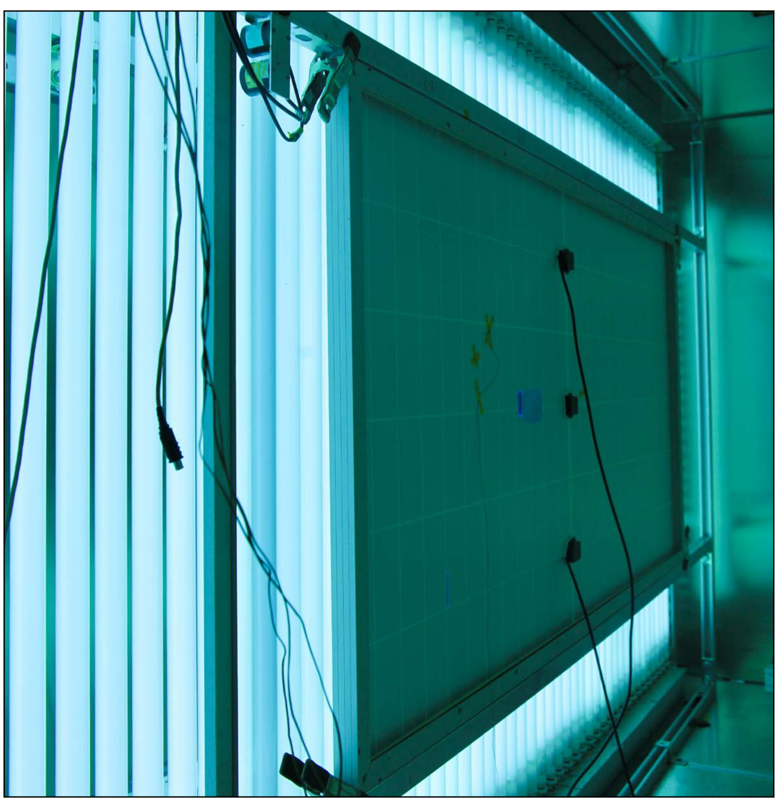
THERMAL CYCLING PROFILE



Source: IEC61215-2 (2016 Edition)

Dynamic Mechanical Load (DML) DML testing characterizes a module's ability to withstand higher wind loads, which are a leading cause of in-field insurance claims. Unlike standard mechanical load (DML) tests, designed to simulate static snow and ice loads, DML testing simulates dynamic push-pull loads. As part of the DML test, modules are subjected to 1,000 cycles of +1,000 Pascal (Pa) and -1,000 Pa loads at a frequency of three to seven cycles per minute. After the application of these dynamic loads, modules are placed in an environmental chamber and subjected to TC50 testing followed by HF10 or HF30 testing. Upon completion of the mechanical and environmental testing, measurements are taken to characterize electrical performance. DML testing is an effective means of detecting structural failures, broken glass, interconnected ribbons, cells, and electrical bond failures. (See p. 16 for module performance distribution data based on DML, TC, and HF test results.)

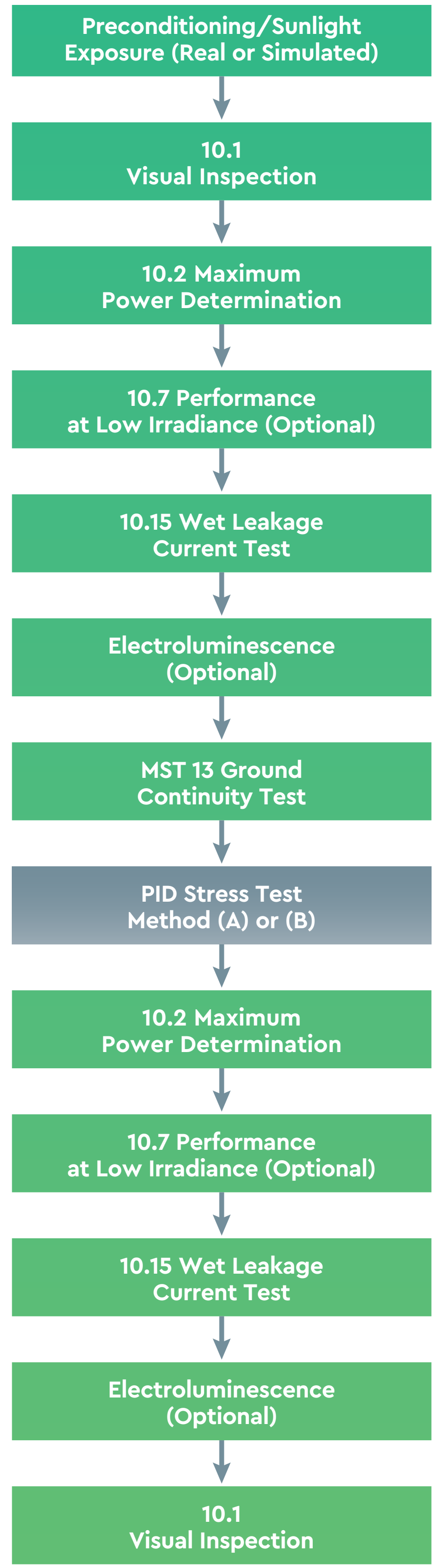
Ultraviolet Exposure (UV) UV soaking or preconditioning is a type of condition test that characterizes a module's susceptibility to degradation and performance loss resulting from exposure to ultraviolet light. The enhanced UV preconditioning test conducted for accelerated reliability assessment exposes modules to two cycles of UV irradiation at 45 kWh/m^2, which is six times greater than the IEC requirements for product qualification. For this test, modules are maintained at an elevated temperature of 60°C and UV light is tuned to the ultraviolet A and ultraviolet B regions. UV exposure is an effective means of detecting failure associated with EVA yellowing, backsheet discoloration, delamination, loss of encapsulation adhesion or elasticity, ground faults due to backsheet degradation, or a general impairment of optics.



DML SEQUENCE

Potential Induced Degradation (PID) PID testing characterizes a module's ability to withstand degradation due to voltage and current leakage resulting from ion mobility between the semiconductor material and other elements of the module packaging. In addition to being accelerated with higher heat and humidity, PID is potentially triggered by system grounding polarity. To conduct PID tests, rack-mounted modules are placed in an environmental chamber, to control temperature and humidity, and exposed to a voltage bias of several hundred volts with respect to the mounting structure. Typically, exposure times range from 96 hours to as much as 500 hours. As the name suggests, this test is an effective means of characterizing a module's susceptibility to potential-induced degradation. (See p. 17 for module performance distribution data based on PID test results.)

PID TEST FLOW



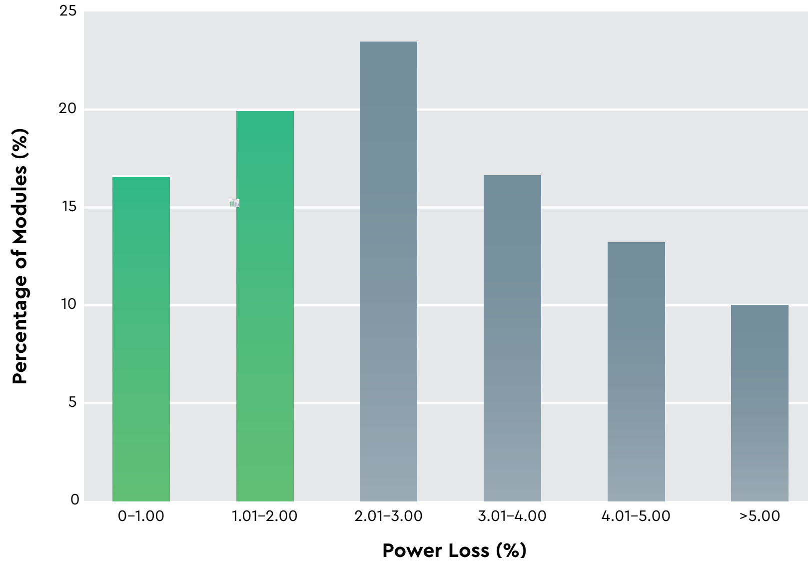
Source: IEC 62804

DH Test Results

For its 2020 edition of the *PVMI* report, RETC has compiled performance distribution data for modules exposed to a 2,000-hour damp heat test (DH2000). To showcase high performance in manufacturing, we have highlighted data for modules that experienced less than 2% power loss. By comparison, IEC and UL certification standards require only a 1,000-hour damp heat test (DH1000) and allow for a maximum performance degradation of 5%.

As shown in these data, nearly 37% of modules that RETC subjected to DH2000 testing in 2019 experienced less than 2% power loss. Additionally, more than 60% of products tested experienced power loss between 2% and 5%, meaning these modules meet the 5% performance degradation allowance in the certification standard in spite of the doubled test duration. The benefit of DH2000 testing, as compared to minimum certification requirements, is that the extended test duration better characterizes module durability and robustness.

2000-HOUR DAMP HEAT (DH2000)



DH2000 - High Achievement in Manufacturing

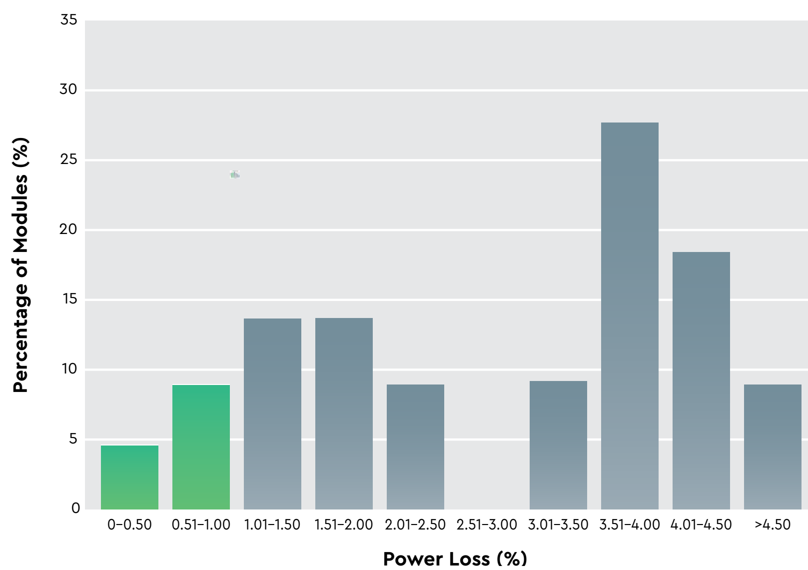
For this edition of the *PVMI,* RETC proudly recognizes the top 25% of modules tested for DH2000. These modules degraded less than 2.0% in this test category and represent excellent robustness and quality in delivered performance. Manufacturers recognized for this achievement are, in alphabetical order: **Jinko Solar** and **LONGi Solar**.

DML Test Results

For its 2020 edition of the *PVMI* report, RETC has compiled performance distribution data for modules exposed to DML testing followed by TC50 and HF10 environmental exposure. To showcase high performance in manufacturing, we have highlighted data for modules that achieved less than 1% degradation in power.

As shown in these test results, more than 12% of the modules that RETC subjected to simulated wind and environmental stresses achieved less than 1% degradation in power. Note that nearly 10% of modules tested experienced more than 5% power loss, suggesting that the test sequence was successful in identifying a potential in-field failure mode.

DYNAMIC MECHANICAL LOAD (DML | TC50 | HF10)



DML Sequence - High Achievement in Manufacturing

Manufacturers achieving lower than 1% degradation in the DML test include: **LONGi Solar.**

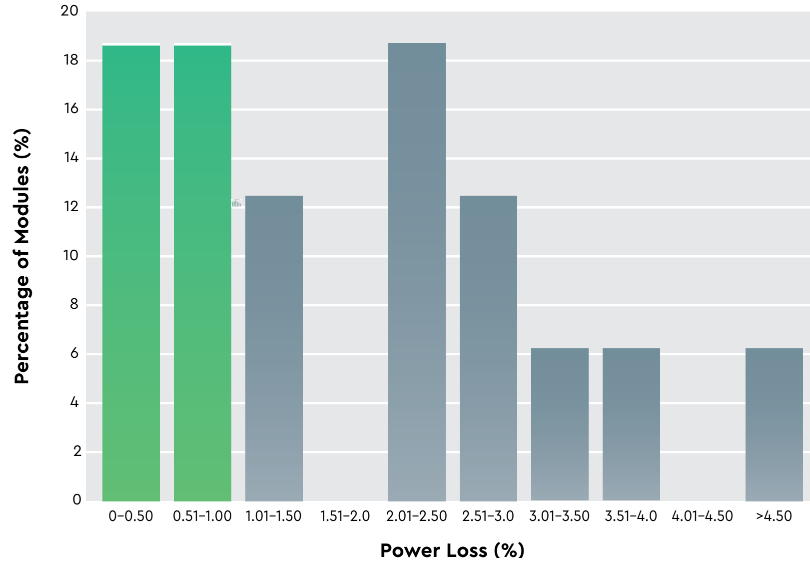
PID Test Results

For its 2020 edition of the *PVMI* report, RETC has compiled performance distribution data for modules exposed to PID testing. To showcase high performance in manufacturing, we have highlighted data for modules that achieved less than 1% of performance degradation through 196 hours of exposure.

While PID failures are less common today than in years past, some cell and module technologies are more susceptible to this type of degradation than others. Nevertheless, it is possible for manufacturers to achieve excellent performance even when using cell architectures with a higher propensity for PID. Research and characterization are useful for identifying appropriate diffusion barriers, lower-sodium glass substrates, high-quality encapsulants, and other processes and materials that optimize performance.

As shown in these data, over 38% of modules achieved less than 1.0% degradation through 196 or more hours of PID test exposure. The benefit of PID-resistant or PID-free modules is that these provide project developers and EPCs with a greater degree of design freedom and flexibility since they are not constrained by PV module grounding requirements.

196-HOUR POTENTIAL INDUCED DEGRADATION



PID – High Achievement in Manufacturing

The manufacturers achieved in the top 50%, less than 1.0% degradation through 196 hours of testing, include, in alphabetical order: **Jinko Solar** and **LONGi Solar.**

Module Performance

Product testing and characterization essential to in-field performance. Manufacturers use sun simulators in concert with other test equipment to characterize PV module performance in the factory under standard conditions, such as a cell temperature of 25°C, irradiance of 1,000 W/m², and an air mass of 1.5. This flash test typically takes place at the end of a production line and allows manufacturers to properly warranty, label, and bin modules before they leave the factory. The resulting power, current, and voltage characteristics are only as accurate as the test equipment and factory controls.

Accredited testing laboratories like RETC have an important role to play in ensuring that module performance characterization is as accurate and reliable as possible. Testing laboratories use calibrated and certified equipment under audited and controlled test conditions. Performance characteristics captured under these rigorous conditions represent the true measure of PV module performance and provide value to multiple project stakeholders.

To provide value to module companies, for example, RETC benchmarks the performance of reference modules that plant operators can use to calibrate factory testing equipment. These so-called "golden modules" are also useful as part of a statistical quality control program. These calibrated reference modules effectively provide a baseline that manufacturers can use to demonstrate that they are meeting or exceeding acceptable limits for output variation.

To provide value to project developers, independent engineers, and financiers, RETC generates third-party validated PAN files that allow for site-specific, plant-level performance evaluation. Conducted to IEC standards, PAN file-characterization tests precisely evaluate module performance under specific operating conditions. Once imported into industry-standard software, such as PVsyst, these independently verified module-specific performance parameters allow for accurate and bankable real-world production estimates.

While factory testing according to STC parameters is ideal for establishing module nameplate ratings, factory test results are not intended to characterize typical module operating conditions. Irradiance conditions in the field are seldom 1,000 W/m² and perpendicular to the plane of the array.

In order to accurately model system performance in the real world, it is essential to understand how modules perform under low-irradiance conditions or in relation to changing sun angles. Likewise, it is important to characterize module performance under test conditions that reflect the real-world operating conditions under which PV systems typically produce optimal energy yields. It is also critical to understand how short-term sun exposure and the resulting degradation impacts in-field PV performance.

Performance Tests & Metrics

As an accredited third-party laboratory, RETC conducts precisely these types of PV module performance characterization tests. Here, we provide a high-level overview of some of the relevant PV module performance parameters that RETC characterizes in its state-of-the art facilities. Following these descriptions, we provide a sampling of performance test results that RETC compiled in 2019 and showcase OEMs according to high achievement in manufacturing.

Module Efficiency Conversion efficiency—the percentage of incident solar energy converted to electrical energy—is a key figure of merit for PV modules and cell technologies. Nominal module efficiency is determined by dividing a product's nameplate STC-rated power capacity by its total aperture area. Cell technology and module design play a large factor in module efficiency. Cell architectures that have demonstrated higher conversion efficiencies include interdigitated back contact (IBC), heterojunction, and passivated emitter rear cell (PERC). Module design features that improve conversion efficiency include bifacialility, half-cut cells, multi-busbar configurations, larger wafer sizes, and shingling to eliminate intercell gaps. (See p. 20 for a ranking of maximum module efficiency ratings calculated per manufacturer based on a year's worth of RETC's module characterization test data.)

CEC Certification In the 1990s, researchers working on the Photovoltaics for Utility-Scale Applications (PVUSA) project developed a set of performance rating parameters intended to simulate environmental conditions a module might experience in the real world. The primary differences between PVUSA testing conditions and standard testing conditions are cell temperature and wind speed. Specifically, PTC parameters call for an elevated cell temperature of 45°C, an ambient temperature of 22°C, and a wind speed of 1 meter per second (2.2 mph). PTC ratings are one of the module performance characteristics that the California Energy Commission requires for CEC listing, a prerequisite for many solar incentive programs. (See p. 21 for a sampling of high-performing PV modules based on PTC-to-STC ratio.)

Incidence Angle Modifier (IAM) IAM is a performance characteristic that accounts for changes in PV module output based on changing sun angles. Optimal transmission of incident sunlight occurs when the solar incidence angle is directly normal (perpendicular) to the surface of the module. As the incidence angle changes, power density decreases due to transmission losses. These transmission losses occur due to reflection at each material interface—air-to-glass, glass-to-EVA, EVA-to-glass—and absorption within the glass itself. To characterize IAM, RETC conducts electrical characterization tests at 13 different incidence angles, ranging from 0° to 90°. IAM testing is essential for understanding module performance at different times or seasons, especially early or late in the day or in winter when the sun is low on the horizon.

PAN Files In order to model plant-level performance based on typical meteorological year (TMY) weather data, industry-standard software tools require component characterization files. The de facto standard module characterization file format is a PAN file, which defines 22 parameters that PVsyst software uses as the basis of its production modeling calculations. PVsyst simulations are an essential tool for industry stakeholders. Project developers use the PVsyst simulations to evaluate potential sites based on energy production and financial performance. IEs use PVsyst to validate the project developer's assumptions. Financial institutions rely on these independent engineering analyses to ensure a return on investment. EPCs and asset managers use PVsyst simulations for capacity testing, commissioning, and plant performance benchmarking. (See p. 22 for module-specific PVsyst performance estimates for a 10 MW ground-mounted application in Texas simulated based on RETC's optimized third-party PAN files.)

Light-Induced Degradation (LID) As the name suggests, LID is a type of degradation resulting from exposure to sunlight. Importantly, LID describes a type of degradation that occurs over a relatively short period of time. LID impacts some PV cell types but not others. PV modules that are prone to LID might experience a relatively rapid rate of performance degradation over a relatively short period of time in the field—typically a few hours or days—prior to performance stabilization. As a service to manufacturers, RETC offers LID testing to IEC standards to ensure manufacturing quality control and in-field reliability. (See p. 23 for a sampling of module performance distribution data based on LID test results.)

Light- and Elevated Temperature-Induced Degradation (LeTID) LeTID is type of long-term in-field degradation that impacts relatively newer cell technologies. While industry efforts are still underway to fully understand LeTID, a correlation has been established between elevated temperatures and increased degradation. Specifically, poly- and monocrystalline Passivated Emitter Rear Cell (PERC) silicon cell architectures exhibit complex cycles of performance degradation and regeneration (recovery) when exposed to elevated temperatures. In response to risks associated with LeTID, downstream stakeholders are paying closer attention to both LID and elevated-temperature testing profiles. The IEC has developed a protocol of light soaking, followed by 75°C temperature exposure for two 162-hour cycles to identify significant degradation (>5%). Subsequently, test samples are subject to 500 hours of 85°C temperature exposure followed by two additional 162-hour cycles, after which measurement should reveal some restoration (regeneration) of module performance. For projects in arid climates, it is important to select modules that experience low initial elevated temperature degradation rates followed by an appropriate regeneration of power.

Conversion Efficiency Results

For its 2020 edition of the *PVMI* report, RETC has ranked the recorded maximum module efficiency values—as well as other relevant product attributes—per manufacturer based on third-party I-V characterization measurements conducted at our accredited testing laboratories over the course of a calendar year. To showcase high performance in manufacturing, we are recognizing those manufactures that achieved conversion efficiencies of 19% or greater based on module area.

MODULE I-V CHARACTERIZATION DATA

Rank	Manufacturer	Model	Technology	Pmax	Module Area (M²)	Module Efficiency
1	A	A	HJT	339.8	1.62	20.9%
2	B	B	HJT	426.1	2.06	20.7%
3	C	C	Mono	403.4	1.95	20.7%
4	B	D	HJT	347.8	1.68	20.7%
5	B	E	HJT	346.2	1.69	20.4%
6	D	F	Mono	381.5	1.88	20.3%
7	E	G	Mono	393.6	1.95	20.2%
8	F	H	Mono	433.8	2.16	20.1%
9	G	I	Mono	326.1	1.63	20.0%
10	E	J	Mono	325.9	1.63	20.0%
11	G	K	Mono	388.8	1.95	20.0%
12	F	L	Mono	361.5	1.81	19.9%
13	B	M	Mono	387.7	1.95	19.9%
14	H	N	Mono	383.8	1.93	19.9%
15	H	O	Mono	415.8	2.09	19.9%
16	H	P	Mono	319.8	1.61	19.8%
17	F	Q	Mono	383.2	1.94	19.8%
18	F	R	Mono	371.7	1.88	19.8%
19	H	S	Mono	380.1	1.92	19.8%
20	A	T	HJT	320.1	1.62	19.7%
21	F	U	Mono	322.0	1.64	19.7%
22	E	V	Mono	381.1	1.94	19.7%
23	I	W	Mono	383.6	1.95	19.6%
24	F	X	Mono	428.7	1.96	19.6%
25	J	Y	Mono	379.1	1.95	19.5%
26	G	Z	Mono	382.0	1.96	19.5%
27	C	AA	Mono	365.9	1.88	19.4%
28	J	AB	Mono	307.1	1.58	19.4%
29	F	AC	Mono	306.6	1.58	19.4%
30	G	AD	Mono	316.4	1.64	19.3%
31	F	AE	Mono	313.8	1.62	19.3%
32	H	AF	Mono	311.5	1.61	19.3%
33	K	AG	Mono	304.4	1.57	19.3%
34	F	AH	Mono	376.9	1.95	19.3%
35	F	AI	Mono	373.9	1.94	19.3%
36	F	AJ	Mono	373.9	1.94	19.3%
37	L	AK	Mono	381.0	1.98	19.3%

Module Efficiency – High Achievement in Manufacturing

Manufacturers that achieved greater than 20% total area module efficiency include, in alphabetical order: **Certain Teed, Hanwha, JA Solar, LONGi Solar, REC Solar, Panasonic,** and **Upsolar Group**.

PTC-to-STC Ratio Results

For its 2020 edition of the *PVMI* report, RETC has ranked the top performing PV modules on PTC-to-STC ratio. To showcase high performance in manufacturing, we are recognizing the manufacture of the Top 10 modules in this list.

Generally speaking, manufacturers with the highest performing products according to this metric utilize cell technologies that experience less power degradation at elevated temperature, which is a function of lower module temperature coefficients.

CEC TESTING DATA

Rank	Manufacturer	Model	Technology	Efficiency	STC	PTC	PTC Ratio
1	A	A	HJT	20.0%	325	309.6	95.3%
2	A	B	HJT	21.0%	340	323.5	95.1%
3	B	C	HJT	21.1%	355	337.2	95.0%
4	B	D	HJT	20.9%	430	407.6	94.8%
5	B	E	HJT	20.7%	350	330.6	94.5%
6	C	F	Mono	19.6%	380	357.7	94.1%
7	C	G	Mono	19.6%	380	357.7	94.1%
8	C	H	Mono	19.9%	435	409.2	94.1%
9	D	I	Mono	19.5%	415	390.2	94.0%
10	B	J	Mono	19.9%	380	357.1	94.0%
11	C	K	Mono	19.3%	430	403.7	93.9%
12	E	L	Mono	19.2%	375	351.8	93.8%
13	C	M	Mono	20.0%	315	295.5	93.8%
14	D	N	Mono	19.8%	385	360.9	93.7%
15	D	O	Mono	19.3%	320	299.7	93.7%
16	F	P	Mono	20.0%	325	304.2	93.6%
17	F	Q	Mono	19.3%	385	360.3	93.6%
18	G	R	Mono	19.3%	335	313.3	93.5%
19	H	S	Mono	20.5%	400	373.9	93.5%
20	B	T	Mono	19.8%	385	359.8	93.5%

PTC-to-STC Ratio – High Achievement in Manufacturing

High-achieving (top 10) PTC ratio manufacturers are dominated by technologies that have lower module temperature coefficients and therefore see less degradation in performance at elevated temperatures. Manufacturers with high achievement include, in alphabetical order: **Hansol Technics, LONGi Solar, Panasonic,** and **REC Solar.**

PVsyst Simulation Results

For its 2020 edition of the *PVMI*, RETC has ranked the top-performing PV modules based on the results of plant-level PVsyst production estimates that use our third-party validated PAN files. To showcase high performance in manufacturing, we are recognizing those manufacturers with products that achieved a PVsyst-modeled performance ratio of 85% or greater.

These simulations assume a theoretical 10 MW utility-scale solar plant in Midland, Texas, deployed using fixed-tilt ground mounts and central inverters with a nominal AC output power rating of 500 kVA. While some design details may vary per simulation—based on product-specific capacity ratings, and so forth—the DC-to-AC inverter loading ratios are equivalent.

PAN FILE TESTING DATA: PVSYST SIMULATION FOR 10MW GROUND MOUNT IN TEXAS

Rank	Manufacturer	Model	Annual kWh/kWp	Performance Ratio
1	A	A	1,935	89.90%
2	B	B	1,913	88.86%
3	C	C	1,882	87.43%
4	B	D	1,873	87.02%
5	C	E	1,871	86.92%
6	A	F	1,853	86.06%
7	B	G	1,818	84.46%
8	D	H	1,815	84.31%
9	D	I	1,813	84.24%
10	D	J	1,807	83.97%
11	E	K	1,807	83.96%
12	F	L	1,804	83.81%
13	B	M	1,804	83.79%
14	G	N	1,800	83.62%
15	D	O	1,798	83.53%
16	B	P	1,797	83.47%
17	H	Q	1,796	83.44%
18	D	R	1,788	83.06%
19	B	S	1,788	83.05%
20	E	T	1,780	82.71%
21	G	U	1,772	82.30%

PAN File – High Achievement in Manufacturers

Three Manufacturers achieved greater than 85% Performance Ratio in this PVsyst Simulation. A noticeable improvement is seen for Manufacturer A which utilized a bifacial technology and achieved simulated results on average 5% greater than more traditional technologies. High Achievers in this category, in alphabetical order: **JA Solar, Jinko Solar, LG, and LONGi Solar.**

LID Test Result

For its 2020 edition of the *PVMI* report, RETC has ranked the top-performing PV modules based on the results of LID testing and characterization. To showcase high performance in manufacturing, we are recognizing the manufacturers of the top 10 modules in this list.

Note that there is some correlation between cell technology and average LID values. Moreover, some products experience an increase—rather than a decrease—in measured power after LID test exposure.

LID TESTING DATA

Rank	Manufacturer	Model	Annual kWh/kWp	Performance Ratio
1	A	A	HJT	1.03%
2	B	B	Mono	0.66%
3	B	C	Mono	0.45%
4	C	D	Mono	0.36%
5	B	E	Mono	0.21%
6	D	F	HJT	0.13%
7	E	G	Mono	0.03%
8	F	H	Mono	-0.05%
9	D	I	HJT	-0.09%
10	E	J	Mono	-0.25%
11	G	K	Mono	-0.30%
12	H	L	Mono	-0.41%
13	D	M	HJT	-0.43%
14	I	N	HJT	-0.52%
15	D	O	HJT	-0.89%
16	J	P	Mono	-0.90%
17	C	Q	Mono	-0.93%
18	J	R	Mono	-1.00%
19	J	S	Mono	-1.01%
20	H	T	Mono	-1.18%
21	E	U	Mono	-1.33%
22	J	V	Mono	-1.40%
23	J	W	Mono	-1.47%
24	K	X	Mono	-1.52%
25	J	Y	Mono	-1.77%
26	L	Z	Mono	-1.82%
27	J	AA	Mono	-1.86%
28	J	AB	Mono	-2.02%
29	J	AC	Mono	-2.02%
30	J	AD	Mono	-2.20%

LID – High Achievement in Manufacturers

Those manufacturers that achieved a top 10 ranking of all modules tested for LID at RETC include, in alphabetical order: **JA Solar, Jinko Solar, LONGi Solar, Neo Solar Power Corporation, Panasonic,** and **Silfab Solar** with several of these participants actually seeing gains or no power losses after exposure times most likely attributed to their specific cell and module technologies.

Module Quality

Accredited third-party testing laboratories are foundational to module quality. At its most basic level, manufacturing quality involves conformance to specifications. RETC plays an important role in these efforts by testing products to relevant IEC, UL, or CEC standards. Experience has shown that simply meeting minimum certification requirements does not ensure a quality product for all project stakeholders.

To address in-field module quality over a 25- or 30-year timeframe, RETC provides a variety of quality assurance (QA) and quality control (QC) services. Beyond-qualification testing, for example, is a quality assurance service that ensures product design and engineering quality. Enhanced testing, including testing to failure, allows manufacturers to identify potential wearout and failure mechanisms prior to volume manufacturing. Once production starts, quality control programs and services ensure product manufacturing quality over time.

Efforts to ensure module quality are neverending. Downward price pressure impacts product designs for better and for worse. On the one hand, this price pressure may increase technology innovation and manufacturing efficiencies; on the other hand, effort to cut costs may have unintended consequences that degrade in-field performance. Moreover, falling system costs result in an expansion of solar project development activities, in some cases to places—such as hail-prone regions of the Continental United States—that present new hazards.

Module Quality

Quality Tests & Metrics

A manufacturing commitment to quality takes many forms. Here we provide an overview of some of the most important components of a successful quality program. Manufacturers that commit to these QA and QC activities demonstrate a commitment to quality. Following this overview, we provide a summary of Thresher Test results and showcase OEMs according to high achievement in manufacturing.

Beyond-Qualification Testing Over the past decade, industry stakeholders and committees have worked continuously to develop more stringent testing protocols designed to better identify long-term module wearout mechanisms and failure modes. Subjecting products to one or more of these enhanced testing protocols is one way that OEMs can demonstrate a commitment to quality.

Products that have passed these beyond-qualification tests are less likely to experience short-term failures and performance degradation in the field. (See p. 26 for a matrix presenting Thresher Test data.)

Product Conformity To improve product performance, reliability, and cost, module manufacturers are continually making bill of material (BOM) and other engineering changes to products and product lines. While product certification standards provide guidance in regards to when re-certification tests are required, these guidelines are not always interpreted correctly or consistently. Moreover, loopholes exist in these guidelines. If a manufacturer's cell part number remains the same, for example, a substantive change to a production recipe—such as a different cell thickness, process temperature, or chamber pressure—may trigger only minimal re-testing requirements. Since these seemingly small process changes could impact long-term reliability and performance, RETC works with customers to help them analyze BOM and engineering changes to determine whether additional testing should take place. These quality control measures increase confidence that a design change does negatively impact in-field reliability. Manufacturers can demonstrate a commitment to quality by being transparent about BOM and engineering changes and adhering to best practices regarding re-testing.

Random Sampling Randomized sampling is a statistical method of ensuring quality control during volume production. As the name suggests, samples are selected at random and inspected or tested to specific standards. Random sampling not only ensures consistency in manufacturing production equipment performance, but also in the upstream material supply chain. A successful random sampling program will specify sample testing frequency and define the sample selection methodology. Not only is random sampling essential for manufacturers to demonstrate a commitment to quality, but it also is a best practice for volume purchasers.

Factory Investigations Third-party solar factory audits and inspections are another way for OEMs to demonstrate a commitment to quality and for volume purchasers to mitigate supply-chain risk. Factory audits typically review factory certifications, resource training, production processes, materials, finished products, and logistics. Factory inspections review product lines, incoming materials, BOM conformty, in-line manufacturing, and warehousing. These factory investigations are increasingly important in a manufacturing ecosystem that is at once global and regionalized. High-quality manufacturers not only establish stringent quality QA and QC standards for first factories, but also propagate these program elements successfully to any other factories manufacturing the same products or module families.

Thresher Test Results

For its 2020 edition of the *PVMI* report, RETC has compiled a summary of Thresher Test results for manufacturers and product models, ranked according to high performance across the most discrete accelerated aging tests. For the purposes of this matrix, high product quality is demonstrated by achieving power degradation of less than 2% for a given test. To showcase high performance in manufacturing, we are recognizing those manufacturers that achieve high performance across multiple accelerated test sequences.

Fielded PV modules are exposed to a wide variety of environmental stresses. Note that some manufacturers put their products through only one or two accelerated reliability tests, which provides limited insight into in-field performance. Manufacturers that characterize modules based on an exhaustive set of accelerated stress tests demonstrate a commitment to quality.

See next page for results table →

THRESHER TEST PERFORMANCE MATRIX

Key: <2% | >2% | No Data

Manufacturer	Model	HF30	TC600	DH2000	DML	UVSoak
B	A	<2%	<2%	<2%	<2%	<2%
A	B	<2%	<2%	<2%	<2%	
A	C	<2%	<2%	<2%	<2%	
A	D		<2%	<2%	<2%	<2%
A	E	<2%	<2%	<2%	<2%	
A	F	<2%	<2%	<2%	<2%	
C	G				<2%	
D	H				<2%	
D	I				<2%	
D	J				<2%	
E	K				<2%	
D	L				<2%	
D	M				<2%	
C	N				<2%	
C	O				<2%	
D	P				<2%	
D	Q				<2%	
D	R				<2%	
D	S				<2%	
D	T				<2%	
F	U			<2%		
D	V				<2%	
D	W				<2%	
B	X		<2%	>2%	<2%	<2%
F	Y	>2%		<2%	<2%	<2%
F	Z	>2%			<2%	<2%
B	AA	>2%			<2%	<2%
D	AB		<2%	>2%	<2%	
G	AC		<2%	>2%	<2%	
G	AD		<2%	>2%		
F	AE	>2%	<2%	>2%	<2%	
F	AF	>2%		>2%	<2%	
F	AG	>2%		>2%	<2%	
F	AH	>2%	>2%	>2%	<2%	<2%
A	AI	>2%	<2%	>2%	>2%	
E	AJ	>2%				
H	AK			>2%		

Thresher Test – High Achievement in Manufacturing

Manufacturers that tested a wide range of accelerated reliability indicators and demonstrated commitment to testing multiple products and changes to individual module family include, in alphabetical order: **JA Solar, Jinko Solar, LONGi Solar, Panasonic, and Trina Solar.**

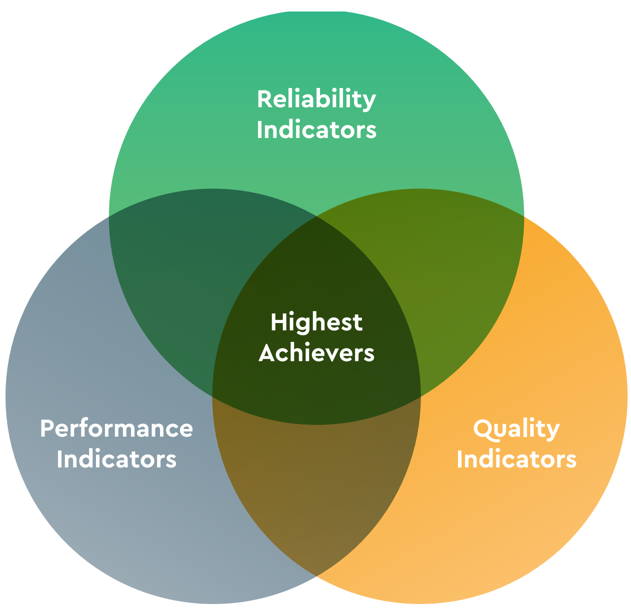
Summary

RETC compiles its annual *PVMI* report as a means of showcasing and recognizing industry-leading PV module companies and technologies. RETC compiled the data and results presented in this white paper at its accredited testing facilities during the 2019 calendar year. Looking ahead to the 2021 edition of the *PVMI*, we expect the general trend toward longer test durations to continue. To better characterize durability, for example, we believe that industry standards for acceptable thermal cycling testing to will increase in duration from 600 cycles to 800 cycles. We also expect that downstream stakeholders will increasingly request or require LeTID characterization, as this test has proven to be a good barometer for PERC type cell technologies.

2020 Overall High Achievers

In the 2020 edition of the *PVMI* report, RETC has recognized 17 different manufacturers in the process of showcasing 40 instances of high achievement in manufacturing in eight different categories. To identify the best of the best, we reviewed and ranked the overall data distributions across all three disciplines: reliability, performance, and quality.

The results of this analysis are summarized in the Overall Results Matrix. Note that this analysis is based on available data. RETC cannot make an overall determination regarding high achievement in manufacturing without module tests data across all three categories. Products and manufacturers that are not on this list may still be robust, reliable, and high-quality. In the absence of test data, RETC is simply unable to make that determination.



2019 OVERALL RESULTS MATRIX

For its 2020 edition of the *PVMI* report, RETC is recognizing four manufacturers for demonstrating high achievement across indicators in all 3 categories of reliability, performance, and quality. RETC congratulates **LONGi Solar, JA Solar, Jinko Solar** and **Panasonic** for their respective performance in the 2020 edition of the *PVMI*.

Key: High Achievement | Average Performance | No Data

Manufacturer	Model	Reliability	Performance	Quality
A	A	High Achievement	High Achievement	High Achievement
B	B	High Achievement	High Achievement	High Achievement
B	C	High Achievement	High Achievement	High Achievement
B	D	High Achievement	High Achievement	High Achievement
B	E	High Achievement	High Achievement	High Achievement
C	F	High Achievement	High Achievement	High Achievement
A	G	High Achievement	Average Performance	High Achievement
D	H	High Achievement	Average Performance	High Achievement
E	I	High Achievement	Average Performance	High Achievement
B	J	High Achievement	Average Performance	High Achievement
D	K	High Achievement	Average Performance	High Achievement
C	L	High Achievement	No Data	No Data
F	M	High Achievement	No Data	No Data
D	N	High Achievement	Average Performance	No Data
D	O	Average Performance	No Data	No Data
D	P	Average Performance	No Data	No Data
G	Q	Average Performance	Average Performance	No Data
G	R	Average Performance	Average Performance	No Data
G	S	Average Performance	Average Performance	No Data
B	T	No Data	High Achievement	No Data
B	U	No Data	High Achievement	No Data
H	V	No Data	High Achievement	No Data
C	W	No Data	High Achievement	No Data
I	X	No Data	High Achievement	No Data
J	Y	No Data	High Achievement	No Data
I	Z	No Data	High Achievement	No Data
I	AB	No Data	High Achievement	No Data
K	AC	No Data	High Achievement	No Data
A	AD	No Data	High Achievement	No Data
L	AE	No Data	High Achievement	No Data
H	AF	No Data	High Achievement	No Data
A	AG	No Data	High Achievement	No Data
I	AH	No Data	High Achievement	No Data

A Snapshot of

2020 High Performance Awardees

Congratulations to our top four achievers per category!

Overall High Achievers

JinKO Solar

JA SOLAR

LONGi

Panasonic

DH2000 - High Achievement Manufacturers

Jinko Solar

LONGi

DML - High Achievement Manufacturers

LONGi

PID-Free – High Achievement Manufacturers

Jinko Solar

LONGi

Module Efficiency – High Achievement Manufacturers

CertainTeed SAINT-GOBAIN

Hanwha

JA SOLAR

LONGi

REC

Panasonic

Upsolar

PTC-to-STC Ratio – High Achievement Manufacturers

Hansol

LONGi

REC

Panasonic

PAN File – High Achievement Manufacturers

Jinko Solar

JA SOLAR

LG

LONGi

LID – High Achievement Manufacturers

Jinko Solar

JA SOLAR

LONGi

NSP

Silfab SOLAR

Panasonic

Thresher Test – High Achievement Manufacturers

Jinko Solar

JA SOLAR

LONGi

Panasonic

Trinasolar

Looking Ahead

Future RETC Services & Responses

Upcoming PV Standards

Standards for PV modules continue to grow in response to the innovations and breakthrough products that come from the best PV module manufacturers. With RETC's long track record, we've identified and compiled a sneak peak into several potential test standards that will be introduced in the near future.

IEC 61215 202x Series Terrestrial photovoltaic (PV) modules - Design qualification and type approval: Test Requirements and Procedures and **IEC 61730 202x Series** Photovoltaic (PV) module safety qualification- Requirements for Construction and Testing

After the consolidation of c-Si and Thin-Film products in the 2016 release, a further improved version is on the way addressing specific issues of testing flexible PV modules, bifacial modules, very large modules and certain anticipated failure modes such as PID/BO-LID/DML.

IEC TS 63126 Guidelines for qualifying PV modules, components and materials for operation at higher temperatures

Defines additional testing requirements for modules deployed under conditions leading to higher module tem- perature which are beyond the scope of IEC 61215-1 and IEC 61730-1 and the relevant component standards, IEC 62790, 62930, 62852, 62788-1-x (Encapsulant), 62788-2-1 (Fronsheets and Backsheets etc. such as BIPV and desert application. Level 1 is for operating temperatures between 70-80 °C while Level 2 is for 80-90 °C where about 10-20 °C respectively are added to temperature conditions in certain tests such as Hot Spot, UV, TC, Bypass Diode Test, Creep, Dry Heat while compliance to applicable component standards is reevaluated.

IEC 63092–1: Building integrated photovoltaic modules (Part 2 is for system)

Describes basic requirements on mechanical stability, fire safety, hygiene, noise protection, energy economy, & heat retention for application categories A to E based on mounting slope, accessibility and location in the building. European counterpart of North American standard UL 7103 referencing to building code requirements

IEC TS 63209-2 Extended-stress testing of photovoltaic modules for risk analysis (IEC 63209-1)

Aimed at providing data for reliability risk analysis, high- lighting potential failure modes through series of extended climatic and mechanical stress tests.

IEC 62938 Non-uniform snow load testing for photovoltaic (PV) modules

Provides a method for determining the direct load-bearing capability of inclined, framed PV module under the influence of inhomogenous snow loads (mechanical load in sequence with 10 Humidity Freeze cycles).

IEC TS 63140 Photovoltaic (PV) modules – Partial shade endurance testing for monolithically integrated products

Intended to excite similar levels of stress as shadows occur in certain cell/cells connected in series according to 3 test types: Use (U) for products bearing warning on efficiency loss due to shadows in its documentation, Misuse (M) blocking about 90% incident light ie: human body, Most Severe Misuse (SM) blocking about 100% incident light (ie: cleaning tool).

IEC 63163 Terrestrial photovoltaic (PV) modules for consumer products - Design qualification and type approval

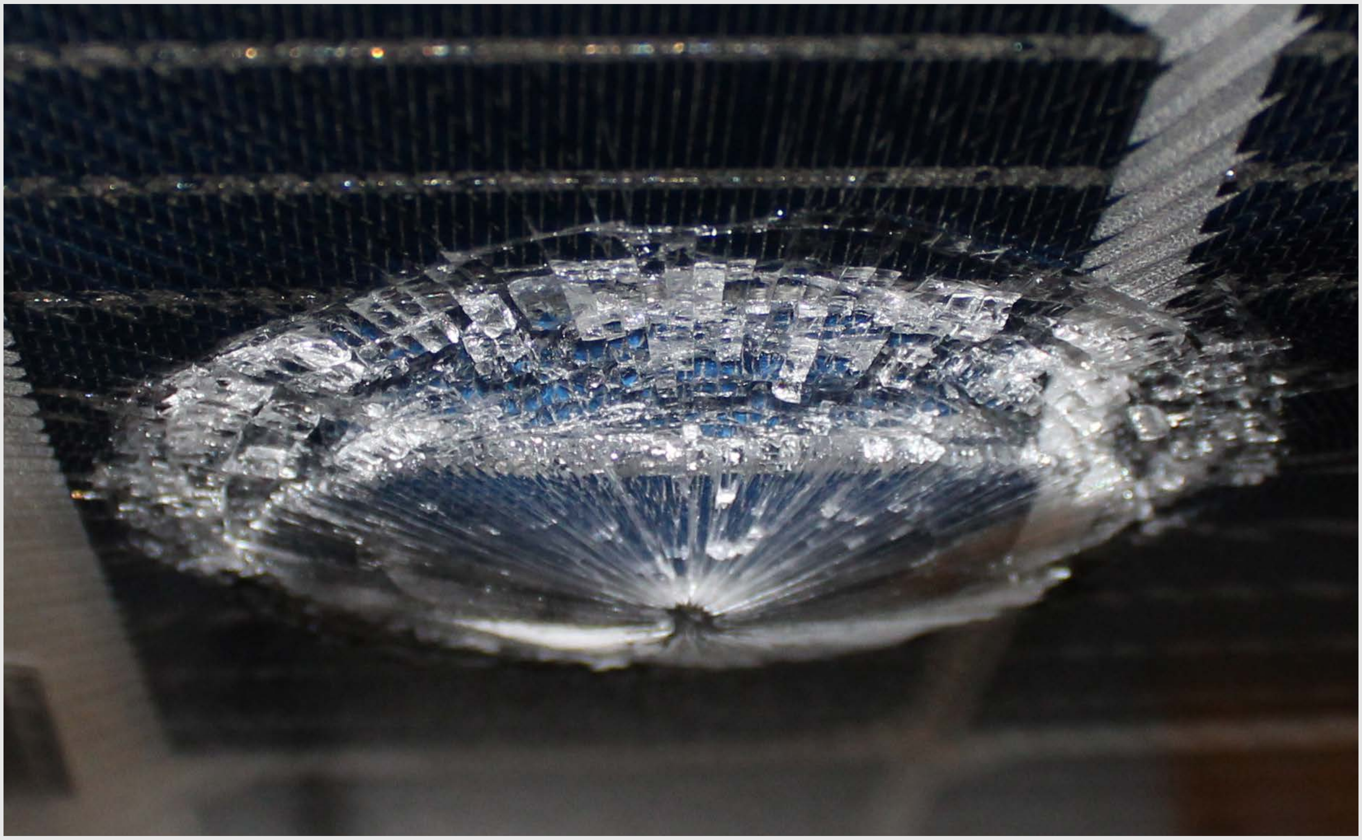
Targeted at consumer PV modules not intended for permanent installation such as mobile, portable products with relatively lower outdoor exposure levels but may be subjected to frequent handling.

IEC 62804-1-1 Test methods for the detection of potential-induced degradation: Crystalline silicon - Delamination

Defines procedures to evaluate for potential-induced degradation-delamination (PID-d) mode in the laminate having one or two glass faces attributable to current transfer between ground and the module cell circuit.

Looking Ahead

Updated Service Offering

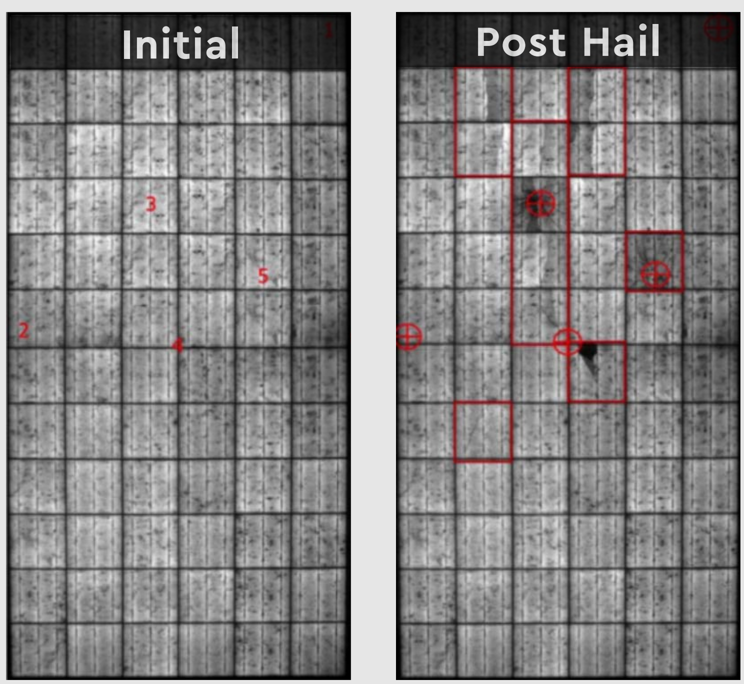


Pictured Above: Resulting PV module damage sustained during the Hail Durability Test.

Hail Durability Test (HDT)

RETC's HDT program assesses the characteristics of the PV Modules and their BOMs and constructions when subjected to installations in hail-prone regions.

The HDT program maximizes test result confidence by using repeatable speeds, consistent ice ball quality, combined with RETC's exclusive environmental chamber testing. The results are categorized by hail size, velocity, resulting kinetic energy (Ke), and a classification of modules of varying grades.



Pictured Right: HDT Result Sample - Module Edge Perimeter • Center of Cell • Edge of Cell Bussing • Ribbon of Cell Area • Free of Cell

RETC

RETC, LLC is a leading engineering services and certification testing provider for renewable energy products headquartered in Fremont, CA. RETC puts customers at the forefront while bringing value at all stages— from R&D, market-entry, to bankability. Since its founding in 2009, manufacturers, developers, and investors have partnered with RETC to test products from a broad range of module, inverter, storage, and racking manufacturers. Only the latest testing standards and industry-accepted methods of vetting products are used in RETC labs. RETC is united by the belief that our work is enabling a safer and more sustainable future.

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