PV Module Index

2019 Edition

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Introduction

RETC is proud to announce the PV Module Index initiative, a yearly compilation of reliability, performance, and quality indices generated in collaboration with leading PV module manufacturers.

As the Solar PV industry has grown mainstream and gone through several technology development cycles, RETC is often asked: "What are the best PV modules and who are the most trusted manufacturing partners?" RETC, with over 10 years of Engineering competency, certification testing, accelerated reliability characterization, and detailed performance analysis, has developed a significant database of data and learning which can be leveraged in an effort to answer this very question.

A good PV module is characterized by how well it performs in various accelerated reliability protocols. A good PV module not only demonstrates high performance in standard test conditions but also performs well in real-world conditions with elevated temperatures, off-angle lighting and over long periods of time. Also, a good PV module is produced by a manufacturer who demonstrates a commitment to quality with disciplined engineering, strict bill of materials (BOM) change controls, and implements consistent and systematic internal and external reliability due diligence over multiple samples to assure all modules rolling off the manufacturing line conform to their specifications.

This annual report highlights three key categories for making a good PV module and choosing a trusted manufacturing partner by showcasing high achievement based on individual testing within each category. The high achievers are manufacturers and/or module families showing excellence in all three categories.

> "What are the best PV modules, and who are the most trusted manufacturing partners?"

Categories for High Achievement

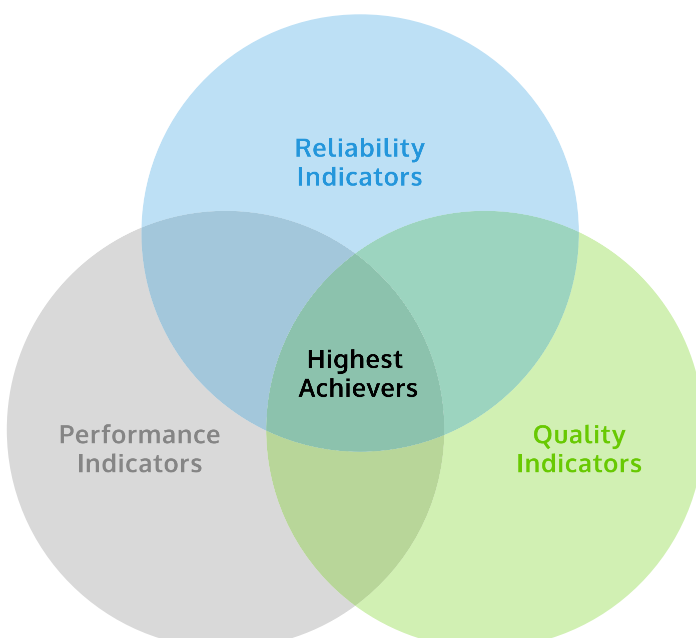
In an effort to showcase the best manufacturers and module families in the industry, RETC is consolidating a report with data compiled annually to cover three distinct categories.

The first category is **Reliability**, where modules are subjected to accelerated testing such as Damp Heat, Humidity-Freeze, Thermal Cycling, Dynamic Mechanical Load, UV Exposure, and Potential Induced Degradation testing. The second category covers **Performance**, which showcases the module's conversion efficiency, how a fingerprint of performance such as a PAN file results in simulated installation scenarios modeled with software packages such as PVsyst, and what levels of degradation can be seen with light exposure and elevated temperatures. Finally, the third category covers the manufacturer’s commitment to **Quality**; do modules perform well over a wide range of tests, are they characterized for changes made by Engineering or with different internal supporting materials, are modules tested with some known frequency or even with randomized sampling techniques.

The manufacturers and module families that demonstrate strong performance in all three of these disciplines showcase high achievement and represent the best the industry has to offer.

Each year RETC will consolidate an annual report which showcases tests and individual indicators within these three categories of Reliability, Performance, and Quality. Data will be shared, showcasing distributed performance within a given indicator. High achievers will be recognized for performance on the high end of the distribution to differentiate from average and poor performers. Achievement can be garnered via individual tests; however, the strongest manufacturers and module families will demonstrate excellence across a wide range of tests that span all categories.

The following sections will showcase the individual indicators tracked annually, and this white paper consolidates data & recognition from testing that occurred at RETC during the 2018 calendar year.



Reliability Indicators

Background

Over the past several years, the industry has developed a rigorous set of standards for compliance to reliability testing, to accelerate aging, and identify possible weakness in a PV module's design, bills of material, or general technology architecture. UL & IEC standards have been in existence and are requirements for modules that are shipped to end customers, however over the past decade, new test protocols were initiated by the industry to assess and address the durability aspects of modules. Examples are Thresher Test, Product Qualification Program (PQP), NREL Product Qualification Plus, and the CSA EXP450, which typically are more aggressive and have longer test durations, usually 2x to 3x of the base IEC compliance requirements.

RETC has been a leader in helping define and develop accelerated reliability test indicators which put additional stress on the modules in order to identify areas of weakness. For the PV Module Index, the following section identifies the tests and metrics that are characterized each year.

Tests & Metrics

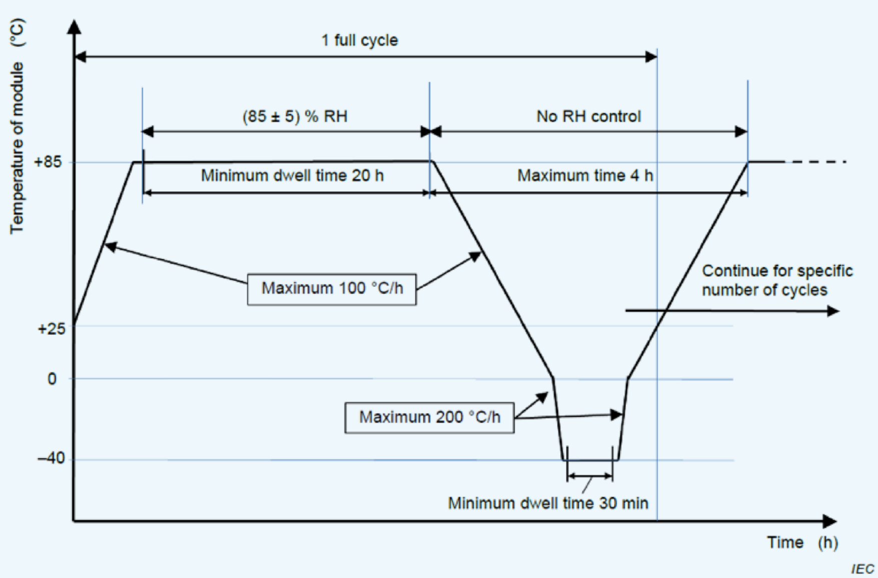
Damp Heat (DH)

Damp Heat testing consists of aging PV modules inside an environmental chamber by exposing them to a controlled temperature of 85 degrees Celsius, and a relative humidity of 85% for a set amount of time. For typical Thresher/PQP testing the duration of exposure is 2,000 hours twice that of typical requirements for product certification. Damp Heat is a good test method to characterize corrosion, delamination, encapsulation loss of adhesion and elasticity, junction box and connector durability, electrochemical corrosion, and general deficiencies in edge deletion. Damp Heat 2,000 hours data is shown in this 2019 edition of the PV Module Index.

Humidity Freeze (HF)

PV modules are subjected to cycling between temperatures of 85°C with relative humidity 85% and -40°C with no relative humidity control. Certification standards call for 10 cycles and less than 5% degradation, whereas during typical Thresher/PQP testing, modules are subjected to an additional 20 cycles for a total of 30 humidity freeze cycles, or 3X the UL and IEC certification requirement. This test is used to characterize junction box and connector durability, proper edge deletion, and delamination.

HUMIDITY FREEZE PROFILE

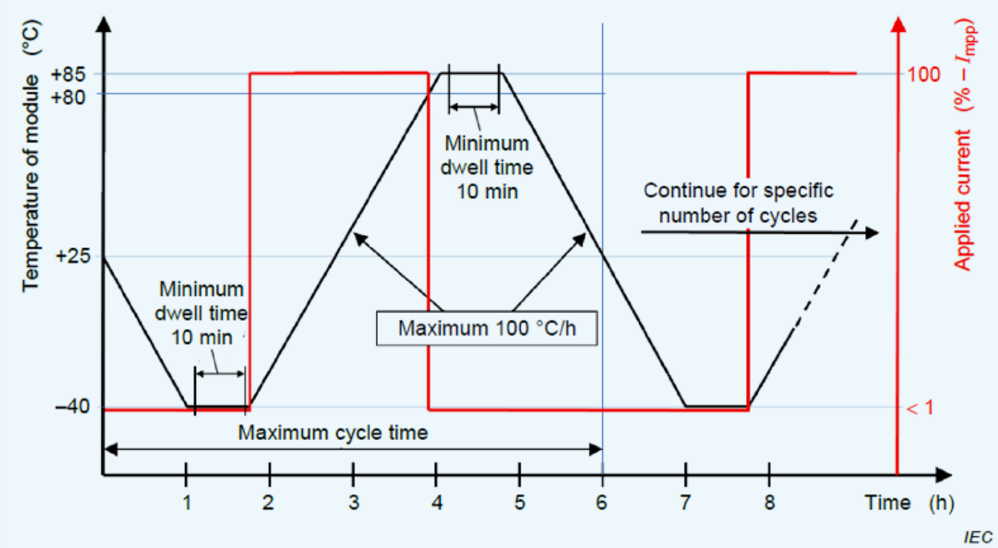


Source: IEC61215-2

Thermal Cycling (TC)

Thermal Cycling tests consist of cycling the modules between 85°C on the high end and -40°C on the low end. Certification standards call for 200 cycles between these two temperatures, however more recent industry norms include extending this thru 600 cycles and even as high as 1000 cycles. Thermal Cycling mechanically stresses the module to detect weaknesses in the module design. Common failures consist of broken interconnects, cracked cells, electrical bond failures, junction box and connector durability, arcing, and the possibilities of open circuits.

THERMAL CYCLING PROFILE



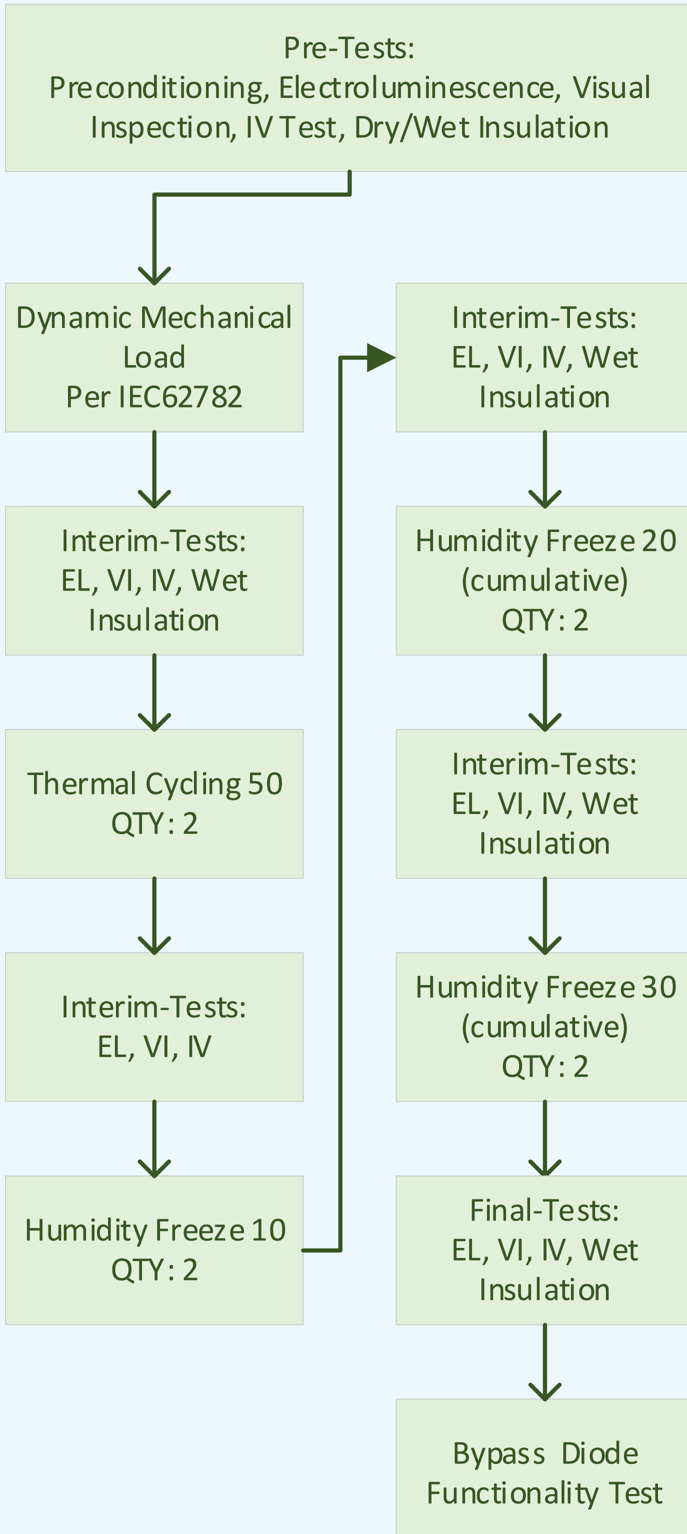
Source: IEC61215-2

Dynamic Mechanical Load (DML)

DML is a cyclic (dynamic) mechanical load test where a 1000 Pa load is applied to the module surface both in the positive (+1000 Pa) and in the negative (-1000 Pa) direction at a frequency of 3-7 cycles per minute for a total of 1000 cycles. The modules are then subjected to Thermal Cycling (TC50) and Humidity Freeze (HF10, normally extended to HF30) environmental stress testing. Measurements are then conducted to characterize the performance and electrical integrity and safety of the modules. The DML sequence helps evaluate if components within the module (including solar cells, interconnect ribbons, and/or electrical bonds) are susceptible to breakage or if edge seals are likely to fail due to the mechanical stresses encountered during installation and operation. Dynamic Mechanical Load sequence data is shared in this 2019 edition of the PV Module Index.

see next page for chart

DML SEQUENCE



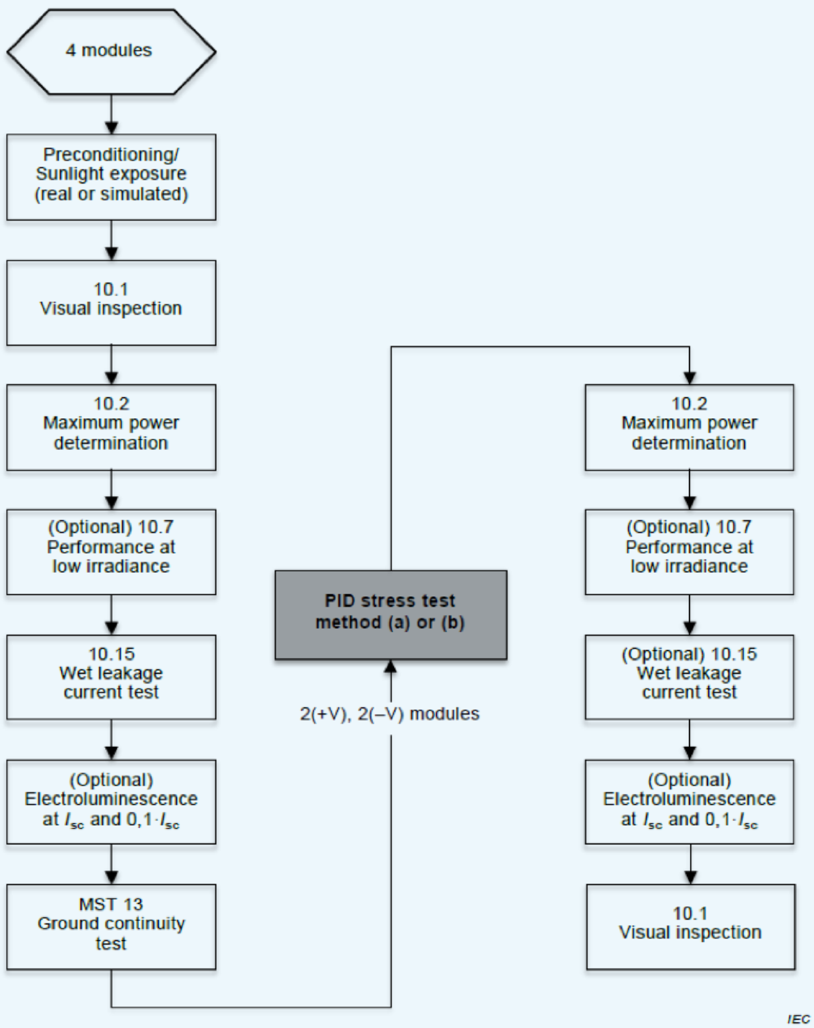
UV Exposure

The UV soak or UV preconditioning test is conducted by exposing modules to two cycles of UV irradiation of 45 kWh/m2, or a total of 6x the IEC requirement. The UV light is tuned in the UVA & UVB regions while maintaining the module at an elevated temperature of 60°C +/-5°C. UV exposure helps detect failure mechanisms such as EVA yellowing, backsheet yellowing, delamination, encapsulation loss of adhesion and elasticity, backsheet discoloration, ground faults due to backsheet degradations and an overall loss of optics.

Potential Induced Degradation (PID)

Potential Induced Degradation, as the name implies, can occur when the module's voltage potential and leakage current drive ion mobility within the module between the semiconductor material and other elements of the module (e.g., glass, mount, and frame), thus causing a drop in the module's power output, in many cases significantly. PID reduces both the module's maximum power point (MPP) and its open circuit voltage (Voc) along with a reduction in shunt resistance. PID testing is conducted with a module inserted into an environmental chamber to control temperature at 85°C and relative humidity at 85%. Modules are exposed to a voltage potential bias between the internal circuit and the module frame. The voltage bias is equal to the maximum system/string voltage relative to the ground/mounting structure. Typically, exposure times range between 96 hours and 500 hours. The results of the PID testing are included in this 2019 PV Module Index report.

PID TEST FLOW



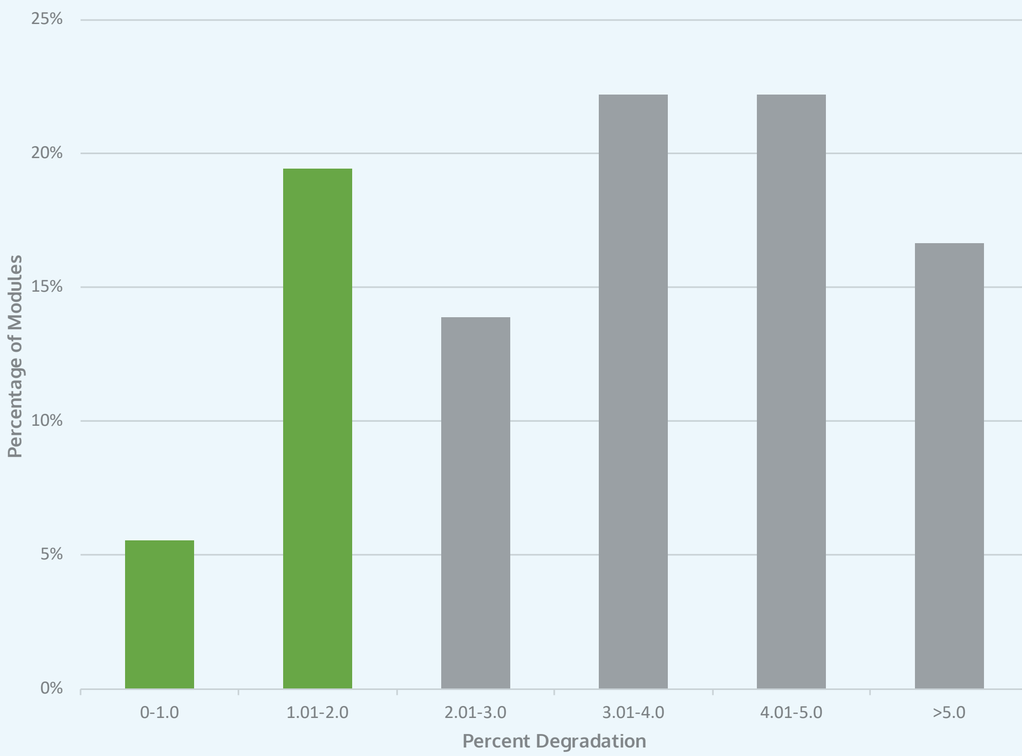
Source: IEC62804

2018 Damp Heat (DH) Results

For this 2019 edition of the PV Module Index report, RETC has compiled module degradation data from various manufacturers showcasing the performance distribution of modules exposed to 2,000 hours of Damp Heat. In contrast, IEC and UL certification standards require only 1,000 hours of Damp Heat and a maximum allowed performance degradation of 5%. DH2000 stress testing from 2018, shown below, expresses the power loss as a percent performance drop during testing.

As can be seen from the data below, nearly 85% of the modules tested in 2018 achieved an acceptable power loss of <5% even with exposure time doubled versus certification standards. For 2019 and beyond, an additional category for 3,000 hours of Damp Heat will be added and used in the Index.

2018 DAMP HEAT 2000HRS



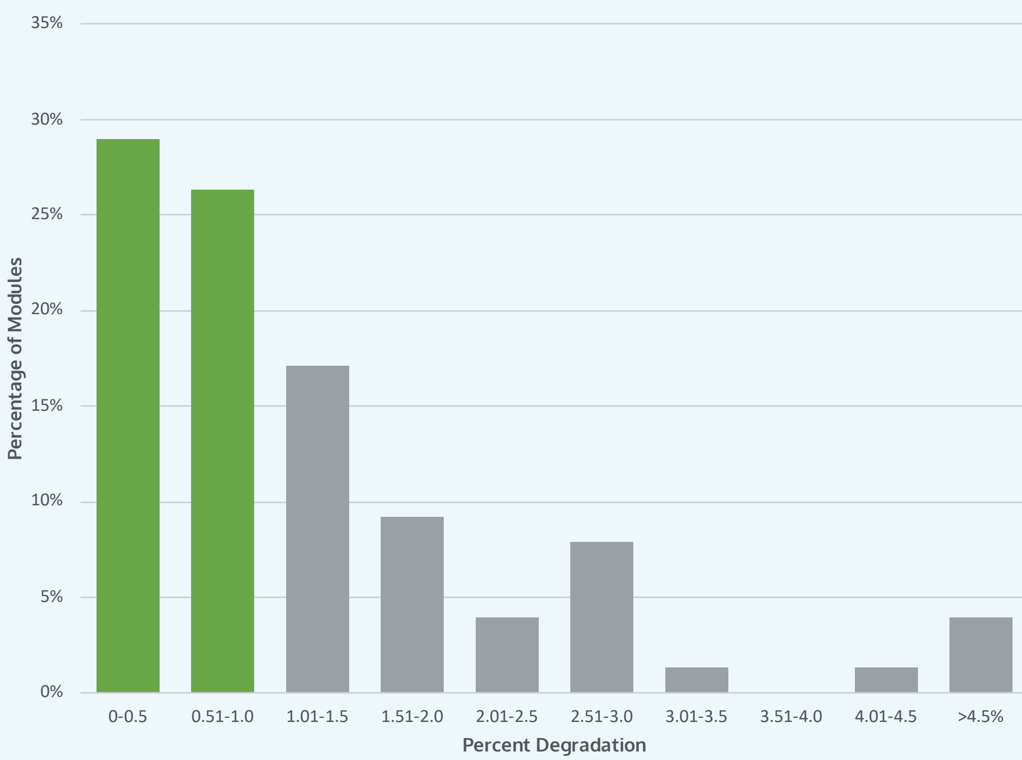
2018 DH2000 - High Achievement Manufacturers

For this edition of the PV Module Index 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 Green Energy Technology.**

2018 Dynamic Mechanical Loading (DML)

The 2018 data compiled for Dynamic Mechanical Load sequence shows a large percentage of modules achieving less than 1% degradation in power with this test. Over 50% of the modules tested achieved this threshold.

2018 DYNAMIC MECHANICAL LOAD SEQUENCE (DML-TC50-HF10)



2018 DML - High Achievement Manufacturers

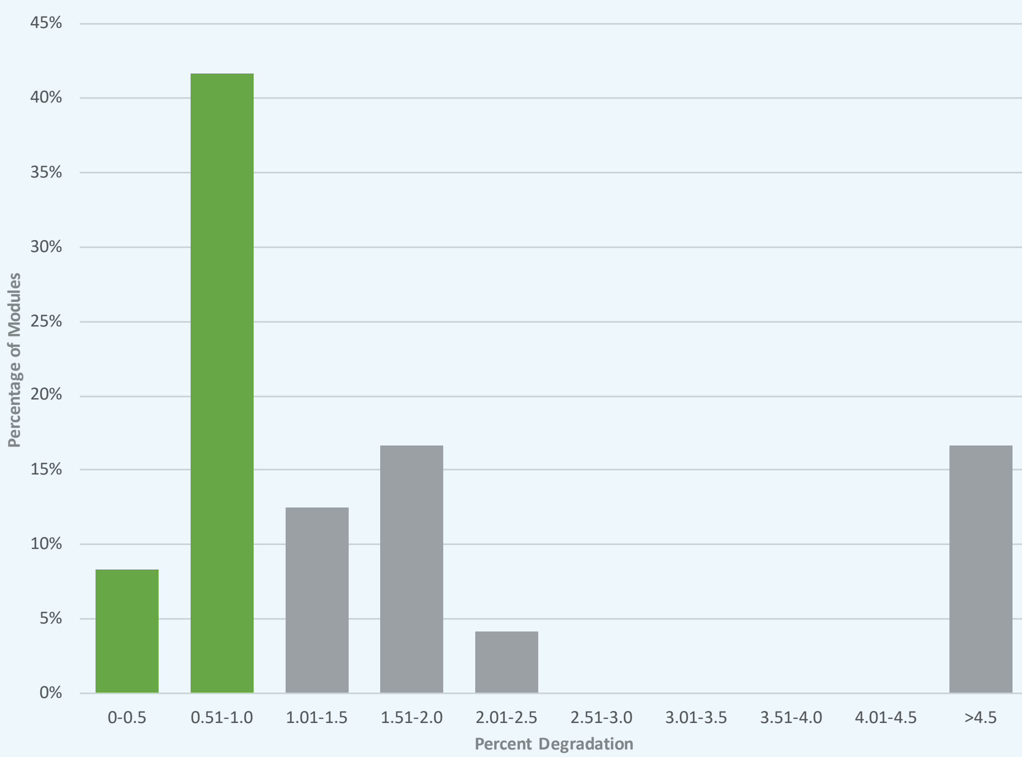
Manufacturers achieving lower than 1% of degradation in the DML test are, in alphabetical order: **Canadian Solar, CertainTeed, Hanwha Q CELLS, Jinko Solar, Longi Green Energy Technology, Mission Solar, Panasonic,** and **Trina Solar.**

2018 Potential Induced Degradation (PID)

For several years, the PV industry experienced a noticeable failure rate related to Potential Induced Degradation in the field. Some of these PID issues were due to improper grounding and mounting in the field, however in many cases, the modules themselves were susceptible to PID. In fact, when the modules are PID resistant or PID free, it provides developers and module installers a higher degree of freedom in designing projects, rather than being constrained by the grounding requirements of the PV modules. PID is accelerated with higher heat, humidity and triggered by the system grounding polarity. Some cell and module technologies can experience higher degradation than others; however, even cell architectures with with PID sensitivity can achieve low PID testing degradations when choosing appropriate diffusion barriers, glass substrates (Lower Sodium levels), and high quality encapsulants.

The 2018 RETC PID testing results show that over 50% of modules achieved less than 1.0% degradation through 196 or higher hours of exposure.

2018 POTENTIAL INDUCED DEGRADATION 196HRS



2018 PID – High Achievement Manufacturers

The manufacturers who achieved in the Top 50%, less than 1.0% degradation through 196 hours of testing, are, in alphabetical order: **Jinko Solar, Longi Green Energy Technology, Merlin Solar, Panasonic,** and **Solar Frontier.**

Performance Indicators

Background

The amount of sunlight that is converted into electricity represents one of the highest figures of merit for a given PV module. To analyze this performance, modules are typically rated at the end of a manufacturing line with a solar tester or solar simulator which flashes a controlled light source and then measures the corresponding module power. This test enables the manufacturer to determine the module power rating used for product labeling and binning.

This labeling, however, only represents the performance of the module at a given time, at specific and controlled test conditions, and is dependent on the accuracy of the manufacturer's test equipment. A better gauge of performance is how much light a PV module converts outdoors in 'real world' conditions. RETC performs various module characterizations to accurately measure PV modules at various test conditions in order to better assess the expected outdoor performance.

The industry has created standard test conditions (STC), which are a fixed set of conditions, where solar panels can be more accurately compared and rated against one another. For STC module measurements, the light source in the laboratory is calibrated so that precisely 1,000 watts per square meter of solar light falls on the photovoltaic panel. The temperature of the solar cells and the ambient room temperature are both set at 25°C. Typically, STC measurements of a given module are created to create a 'Golden' or 'Reference' module which can then be returned to a manufacturing site to help calibrate the local Solar Tester to demonstrate equivalent performance or performance within given statistical and industry accepted variations.

Performance testing at STC allows for a controlled comparison of modules based on their nameplate rating. However, this is only a small factor in determining the overall performance of the module in 'real world' conditions. Modules will behave differently depending on how many hours they've been exposed to light and heat. Typical module technologies will experience Light Induced Degradation (LID) where modules will degrade at a large rate as they cure or settle. Modules will also perform differently depending on the environmental conditions such as ambient temperature and their ability to trap light at steep angles, referred to as the incidence angle.

To understand how modules perform in various conditions of light and elevated temperatures, modules will go through a fingerprint of various conditions and corresponding result by creating what is called a 'PAN' file. PAN files are then inserted into simulation software to help forecast how much energy will be generated for a given environment over a given amount of time. One such simulation package is PVsyst which is a tool used by nearly every solar developer to understand the performance of a given technology, in a given installation setting, factoring in known environmental conditions such as the weather.

Lastly, PV modules can be characterized in actual installation conditions over a given period of time (Field Testing). This represents the best-known method for understanding PV module performance, however, this scenario takes time to analyze and requires consistent maintenance of the system and the module's themselves (i.e., are modules cleaned, if so, how frequently). Therefore, because of these circumstances, laboratory testing at STC conditions as well as simulated conditions such as varying light & temperatures are deemed to be the most readily available indicators of comparing a module's performance.

RETC, therefore, does third party testing of these laboratory and outdoor testing indicators. For the PV Module Index, the following tests and metrics are conducted and compiled each year.

Tests & Metrics

Module Efficiency

Module efficiency is defined as the ratio of the module nameplate maximum power at standard test conditions (STC) over the total area of the module. Cell and module technologies play a large factor in module efficiency levels. Cell architectures such as Interdigitated back contact (IBC), heterojunction, and passivated emitter rear cell (PERC) often demonstrate higher efficiencies. In addition, utilizing larger surface area cells, cut or half-cell configurations, shingling, and bifacial technologies can be integrated to generate better module efficiencies.

CEC Testing – PVUSA Test Conditions (PTC)

PTC was developed by the National Renewable Energy Laboratory (NREL) to come up with a methodology to evaluate solar panel performance under ‘real world’ conditions. The conditions were called ‘Photovoltaics for Utility Scale Applications Test Conditions’ or PVUSA Test Conditions (PTC).

For PV module buyers to qualify for local, state, and federal tax incentives in California and other states, modules go through a series of tests required by the California Energy Commission (CEC). CEC testing is designed to determine the real energy rating of PV modules at PTC. Unlike STC, which requires controlling the module cell temperature at 25°C, PTC requires rating the module at 45°C based on a 20°C ambient temperature and wind speed of 1 meter per second (2.2mph). PTC ratings have shown to be a better gauge of output power and energy generation by modules installed in the field. A PTC ratio is the ratio of the module performance at PTC over its performance at STC. RETC has compiled the top PTC values and the top PTC ratios in the 2019 PV Module Index to showcase modules that have high achievement in ‘real world’ type conditions.

Incidence Angle Modifiers (IAM)

The IAM (Incidence Angle Modifier) is the transmission deficit (up to the solar cell) due to the incidence angle. The transmission loss is a general phenomenon, due to the reflection and transmission of the sun’s rays at each material interface (air-glass, glass-EVA, EVA-cell), as well as some absorption in the glass itself. Measurements are conducted at different incidence angles from 0 to 90 degrees. IAM testing is a good test to understand module performance at different sun angles.

PAN Files – PVsyst Simulation

As mentioned, PAN file testing simulates the performance of modules with varying amounts of irradiance and at various temperatures to fingerprint a module’s potential performance in varying ‘real world’ conditions. Irradiance patterns and temperature profiles shift dependent on daily weather patterns but also show sizeable changes dependent on the season of the year. Output generation during summer months will exceed levels seen in the wintertime. PAN files which characterize modules at 22 different conditions are used in PVsyst simulation software packages to model expected energy output over a given time period. These simulations are critical tools for Project Developers, EPCs, and Financial Institutions to model system performance and evaluate potential solar system project returns. For 2019, the PV Module Index report ranks PAN files measured at RETC and then inserted into a PVsyst simulation of a 10MW ground mount installation in the state of Texas.

Light Induced Degradation (LID)

A well-known performance indicator for the PV project's energy generation is a module's expected Light Induced Degradation (LID) results. Many solar cell technologies can experience early degradation when they are exposed to sunlight. Often times this degradation is much higher than what would be expected after a long period of exposure. Also, system performance directly after installation is a closely monitored time, so large degradation can impact the view of project performance and result in required on-site troubleshooting. IEC 63202-1 states that LID should be observed after an initial irradiance dosage of 20 kWh/m^2, but typical testing will go through 40-100 kWh/m^2 of light exposure and performance will degrade anywhere from 0 to 3%. Some cell technologies are less prone to degradation with exposure and in the case of CIGS technology one might see performance increases with early light exposures. For 2018, the PV Module Index ranks the module's measured for LID, with the high achievers typically being technologies that are not prone to degradation with light exposure.

Light and Elevated Temperature Induced Degradation (LeTID)

Downstream Project Developers, EPCs, and Financial Institutions have been paying closer attention to Light and Elevated Temperature Induced Degradation (LeTID) and its impact on the projected long-term energy yield. With the emergence of Passivated Emitter Rear Cell (PERC) for poly and mono-crystalline silicon cell architectures, a degradation and a corresponding regeneration can be seen when modules are exposed to elevated temperatures. RETC evaluated LeTID performance of various module manufacturers using the conventional method of exposing PV modules to a steady state light source at an elevated temperature as well as the latest IEC 61215-2 draft:2018 protocol. RETC expects to summarize more of these results for future editions of the PV Module Index as well how the industry is interpreting these results and their importance.

2018 Module Efficiency

PV Module Power measurements at STC are used to establish a baseline performance for certification by laboratories and is used by the manufacturers to determine suitable module family binning for commercial sale. RETC has compiled the following dataset of top performance module efficiencies measured during the 2018 calendar year. Many of these modules are from new technology providers who are focused on increasing module performance through different cell architectures (Technology) and module packaging techniques.

2018 MODULE IV CHARACTERIZATION

Rank	Manufacturer	Model	Technology	Pmax	Module Area (M^2)	Module Efficiency
1	A	A	Mono	413.1	2.10	19.67%
2	B	B	HJT	311.8	1.60	19.49%
3	C	C	HJT	315.0	1.62	19.44%
4	C	D	HJT	315.0	1.62	19.44%
5	D	E	Mono	378.9	1.95	19.43%
6	E	F	Mono	364.2	1.88	19.37%
7	E	G	Mono	304.2	1.58	19.22%
8	F	H	Mono	361.6	1.88	19.21%
9	G	I	Mono	374.8	1.95	19.20%
10	G	J	Mono	403.6	2.11	19.14%
11	F	K	Mono	301.0	1.58	19.11%
12	H	L	Mono	303.7	1.60	18.98%
13	I	M	Mono	306.6	1.62	18.96%
14	H	N	Mono	361.7	1.91	18.94%
15	G	O	Mono	303.5	1.61	18.91%
16	J	P	IBC	379.7	2.01	18.89%
17	K	Q	Mono	354.0	1.88	18.83%
18	L	R	Mono	361.3	1.92	18.82%
19	L	S	Mono	392.8	2.09	18.79%
20	G	T	Mono	295.9	1.58	18.73%
21	H	U	Mono	299.6	1.60	18.73%
22	D	V	Mono	302.6	1.62	18.68%
23	L	W	Mono	355.6	1.92	18.52%
24	L	X	Mono	296.1	1.61	18.39%
25	G	Y	Mono	356.5	1.95	18.26%
26	H	Z	Mono	339.5	1.88	18.06%
27	M	AA	Mono	349.7	1.94	18.02%
28	H	AB	Mono	339.0	1.91	17.75%
29	M	AC	Mono	288.5	1.63	17.73%
30	M	AD	Mono	343.0	1.94	17.68%
31	E	AE	Poly	328.5	1.88	17.44%
32	N	AF	Mono	273.4	1.58	17.30%
33	L	AG	Poly	323.8	1.92	16.86%
34	O	AH	Poly	326.1	1.94	16.81%
35	L	AI	Poly	269.0	1.61	16.71%
36	O	AJ	Poly	270.6	1.63	16.60%
37	P	AK	Mono	109.1	0.66	16.45%

2018 Module Efficiency – High Achievement Manufacturers

Manufacturers that achieved greater than 19% total area module efficiency in 2018 are, in alphabetical order: **Hanwha Q CELLS, JA Solar, Longi Green Energy Technology, Panasonic, Solaria, Sunpreme,** and **Yingli.**

2018 PVUSA Test Conditions (PTC)

PTC ratings that were conducted for CEC listing projects in 2018 are listed below.

2018 CEC TESTING

Rank	Manufacturer	Model	Technology	Efficiency	STC	PTC	PTC Ratio
1	A	A	HJT	20.6%	420.0	399.6	95.15%
2	B	B	HJT	20.6%	325.0	308.8	95.02%
3	A	C	HJT	18.2%	300.0	283.7	94.56%
4	A	D	HJT	19.5%	370.0	349.2	94.38%
5	A	E	HJT	18.5%	360.0	339.6	94.34%
6	C	F	a-Si	6.6%	52.0	49.0	94.29%
7	A	G	HJT	19.6%	380.0	357.9	94.19%
8	A	H	HJT	19.8%	320.0	300.1	93.78%
9	D	I	CIGS	13.4%	315.0	295.1	93.70%
10	E	J	Mono	19.4%	410.0	383.3	93.49%
11	F	K	HJT	19.4%	310.0	289.7	93.44%
12	G	L	Mono	19.2%	310.0	289.6	93.43%
13	H	M	Mono	19.6%	310.0	288.4	93.03%
14	H	N	Mono	19.7%	370.0	343.6	92.87%
15	J	O	Mono	19.3%	370.0	343.3	92.78%
16	K	P	Mono	19.0%	300.0	278.2	92.73%
17	L	Q	Mono	19.1%	310.0	287.4	92.72%
18	E	R	Mono	18.6%	295.0	273.4	92.68%
19	H	S	Poly	16.5%	320.0	296.5	92.65%
20	L	T	Mono	19.5%	380.0	352.0	92.63%

2018 PTC Ratio – High Achievement Manufacturers

High achieving (Top 10) PTC ratio manufacturers in 2018 are dominated by technologies that have lower module temperature coefficients and therefore see less degradation in performance at elevated temperatures. Manufactures with High Achievement are, in alphabetical order: **Eterbright Solar Corporation, Longi Green Energy Technology, SolarTech Universal,** and **Sunpreme.**

2018 PAN File – PVsyst Utility Scale Simulation

PAN files were generated at RETC during the 2018 calendar year and used to perform PVsyst simulations focused on energy output for a theoretical 10MW utility scale installation. The project is set in Midland, Texas, at a latitude of 31.95°N and a longitude of -102.09°W as well as an assumption of 0-meter altitude and 0.2 Albedo. A fixed tilt installation utilizing central inverters operating between 460-850V with a 500kWac nominal power were also held constant for the analysis. Module PAN files were inserted and the size of the installation was chosen to be 10MW. Appropriate quantities of modules were then selected to achieve that output. A summary of the data is compiled below.

2018 PAN FILE TESTING - 10MW TEXAS GROUND MOUNT PVSYST SIMULATION

Rank	Manufacturer	Model	Annual kWh/kWp	Performance Ratio
1	A	A	1,949	90.51%
2	A	B	1,947	90.41%
3	A	C	1,947	90.40%
4	A	D	1,942	90.17%
5	B	E	1,848	85.83%
6	C	F	1,831	85.04%
7	D	G	1,830	85.01%
8	A	H	1,830	84.98%
9	C	I	1,826	84.82%
10	A	J	1,826	84.78%
11	C	K	1,824	84.70%
12	E	L	1,823	84.64%
13	E	M	1,819	84.47%
14	C	N	1,817	84.38%
15	A	O	1,816	84.34%
16	D	P	1,811	84.09%
17	C	Q	1,806	83.85%
18	E	R	1,805	83.83%
19	D	S	1,805	83.82%
20	F	T	1,798	83.48%
21	G	U	1,788	83.05%
22	E	V	1,784	82.85%
23	A	W	1,777	82.55%
24	A	X	1,773	82.33%

2018 Pan File – High Achievement Manufacturers

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

2018 Light Induced Degradation (LID)

Performance in LID testing at RETC is summarized in the data table below.

2018 LID TESTING

Rank	Manufacturer	Model	Technology	Average LID
1	A	A	CIGS	1.38%
2	B	B	HJT	0.81%
3	C	C	Mono	0.29%
4	B	D	HJT	0.23%
5	B	B	HJT	-0.02%
6	B	D	HJT	-0.17%
7	D	E	Mono	-0.28%
8	E	F	Mono	-0.47%
9	C	C	Mono	-0.52%
10	E	G	Mono	-0.61%
11	F	H	CdTe	-0.78%
12	C	I	Mono	-0.79%
13	G	J	Mono	-0.81%
14	G	K	Mono	-0.89%
15	C	L	Mono	-0.98%
16	E	M	Mono	-0.99%
17	H	N	Mono	-1.07%
18	H	O	Mono	-1.08%
19	I	P	Mono	-1.16%
20	I	Q	Mono	-1.20%
21	I	R	Mono	-1.28%
22	I	S	Mono	-1.34%
23	J	T	Mono	-1.35%
24	H	U	Mono	-1.36%
25	H	V	Mono	-1.38%
26	H	W	Mono	-1.40%
27	H	X	Mono	-1.41%
28	H	Y	Mono	-1.47%
29	K	Z	Mono	-1.59%
30	D	AA	Mono	-1.59%
31	D	AA	Mono	-1.70%
32	L	AB	Mono	-1.95%
33	H	AC	Mono	-1.99%
34	H	AD	Mono	-2.04%

2018 LID – High Achievement Manufacturers

Those manufacturers that achieved a Top 10 ranking of all module's tested for LID at RETC are, in alphabetical order: **JA Solar, Longi Green Energy Technology, Mission Solar, Panasonic,** and **Solar Frontier** 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.

Quality Indicators

Background

A 'commitment to quality' can mean many different things to different manufacturers and different end users of products. Quality products should be well manufactured with repeatable processes, materials, production equipment, and labor techniques. Quality products should also be well characterized up-front in terms of product release and also characterized throughout their product run to assure disciplined manufacturing process controls. Quality products that go through changes in terms of Engineering improvements and/or bill of material changes should also see disciplined reliability and performance characterization to assure new changes do not offset longevity and repeatable production outputs.

For the PV Module Index, RETC works with both upstream and downstream PV players to help develop appropriate methodologies, tests for extensive characterization and continues to analyze long-term performance and reliability in correlation with upfront laboratory characterization. Manufacturers that commit to a broad range of characterization are believed to have a high level of commitment to building quality products.

Tests & Metrics

PQP/Thresher Testing

Over the past 10 years, there has been a focus to continue to drive more stringent reliability & accelerated testing to identify weakness in modules and potential long-term areas for failure. The industry has developed two related methodologies to this entail. The first is 'Thresher' testing, which takes elements from IEC/UL certification and extends the criteria to further characterize the module. The second is referred to as the Product Qualification Program (PQP) which similarly has its inherent reliability tests coming from IEC/UL certification but requires more stringent durations. Individual tests have been covered in the Reliability section of this report. To demonstrate a 'Commitment to Quality' manufacturers who demonstrate the ability for the same module family to pass not just one PQP/Thresher individual test but demonstrate that the same product can pass a widespread number of tests are identified as High Achievers. For 2018, RETC has summarized by manufacturer and model (product family) what tests have been conducted and who has achieved good results across the entire matrix of tests conducted in PQP/Thresher testing.

Engineering & Bill of Material Changes

Module manufacturers make changes to products on a frequent basis to improve product efficiency (power output), to enhance longevity, and to reduce overall production costs. IEC/UL product certifications have guidelines which denote when re-certification tests are required, however, many of these guidelines are not interpreted correctly and there are loopholes which can trigger inadequate testing. As an example, if a change is made to a crystalline silicon solar cell such as a production process recipe with a different thickness, temperature, and/or chamber pressure, and the manufacturer did not change the cell part number, certification re-test requirements are not triggered. It is entirely possible that these process changes could impact long-term reliability and performance. RETC works with customers to help them analyze their changes to see if additional testing should take place in order to have confidence that a change does not compromise the reliability of their products. Those manufacturers that show a commitment towards testing their specific changes are noted as demonstrating high levels of commitment to quality.

Randomized Sampling

Similar, to the narrative discussed in the change control process above, randomized sampling is another means to demonstrate a commitment to quality and control over product performance. Often times manufacturing production equipment can change performance over time, and material suppliers upstream of module manufacturers may make changes or see a variation in their production equipment. Without a frequency of testing or a randomized selection methodology of product to test, risks in terms of reliability and long-term lifetime may arise. Manufacturers and downstream end users of modules can implement regimented randomized sampling to demonstrate high levels of quality.

Factory Audits & Inspections

With the emergence of global manufacturing locations and in many cases regionalized manufacturing (producing the product close to where it is installed), there becomes an importance to make sure that the manufacturing process, operator training, equipment calibration, qualification, and bills of materials are consistent for a given module product line and the various manufacturing locations where it is produced. Those manufacturers that drive stringent fingerprinting of first factories, and then propagate those same processes, methods, equipment and materials to other factories that produce the same product or module families are seen as high-end quality manufacturers.

2018 PQP/Thresher Testing

For this year's report, a summary of manufacturers and modules (models) subjected to the Thresher/PQP testing are shown below. What is noteworthy is that high achieving quality module manufacturers put their products through an exhaustive set of accelerated reliability tests, while other manufacturers choose to select only a few of the tests to characterize their product. Less than 2% in degradation for a given test demonstrates high achievement and the top end of the distribution of RETC data, >2% represents average performance, and models in tests are designated in blue shade as testing was on-going between 2018 & 2019.

RETC's belief is that modules that demonstrate good results across the entire gamut of PQP/Thresher testing represent the most well characterized products and those manufacturers that implement this methodology demonstrate a high commitment to quality practices.

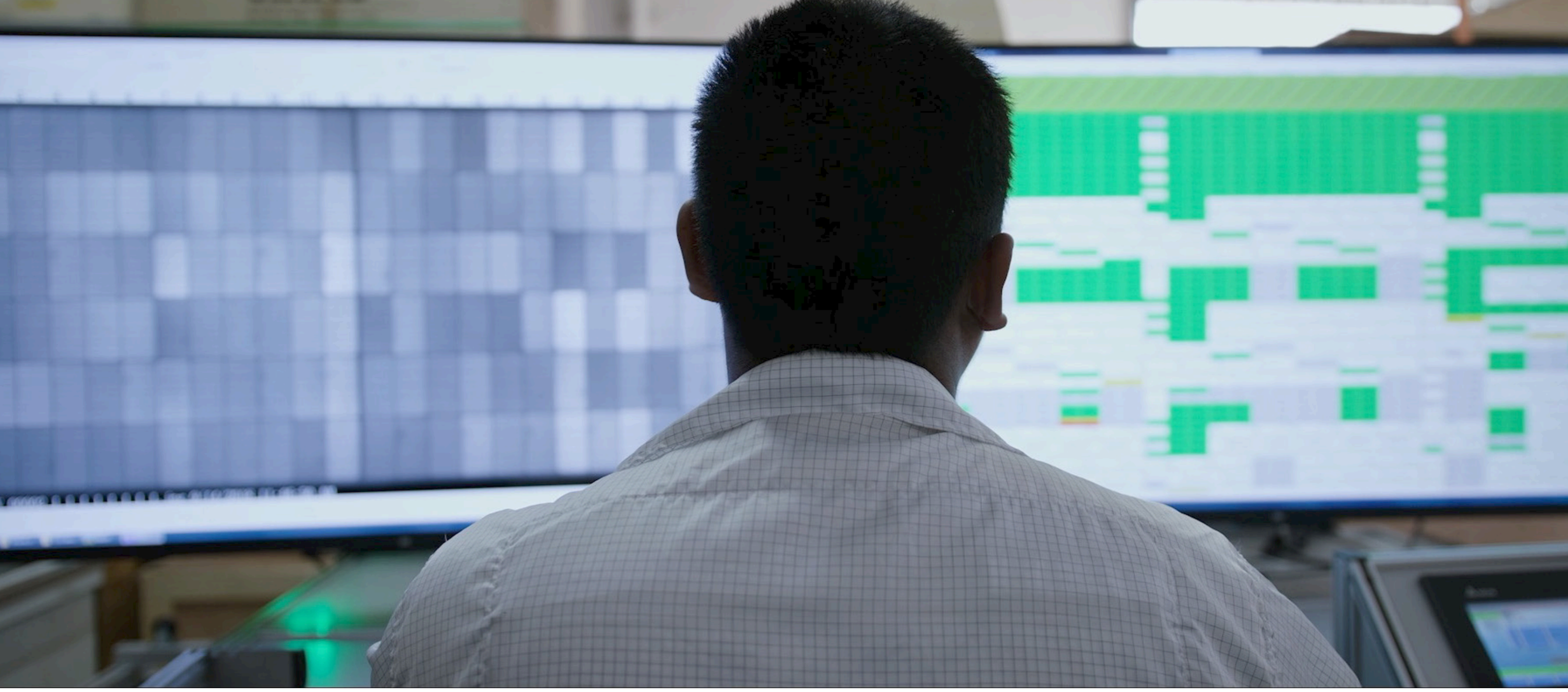
2018 THRESHER/PQP PERFORMANCE MATRIX

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

Manufacturer	Model	HF30	TC600	DH2000	DML	PID	UVSoak
A	A		<2%	<2%	<2%	<2%	<2%
B	B	<2%	<2%	<2%	<2%	<2%	
C	C		<2%	> 2%	<2%	<2%	<2%
B	D	<2%	<2%	<2%	<2%	> 2%	
D	E		<2%	> 2%	<2%	<2%	<2%
B	F	<2%	<2%	<2%	<2%	> 2%	
E	G		<2%				
F	H					<2%	
C	I		<2%				<2%
G	J				<2%		
H	K				<2%		
H	L				<2%		
I	M				<2%		<2%
C	N			> 2%	<2%		<2%
J	0				<2%		
K	P				<2%		
A	Q				<2%		
A	R		<2%	> 2%		<2%	
C	S			> 2%	<2%		
K	T						
F	U	> 2%				<2%	
A	V		in Test	in Test	<2%		> 2%
				> 2%	in Test		in Test
A	W				<2%		
L	X						
A	Y		<2%	> 2%	> 2%	> 2%	<2%
M	Z					> 2%	
F	AA					> 2%	
F	AB			> 2%			
A	AC		in Test	in Test	in Test	in Test	in Test
				> 2%		> 2%	
N	AD					in Test	
A	AE		in Test	in Test	in Test	in Test	in Test
B	AF	in Test	in Test	in Test	in Test	<2%	
B	AG	in Test	in Test	in Test	in Test		
B	AH	in Test	in Test	in Test	in Test	<2%	
M	AI	> 2%	in Test	in Test	<2%	> 2%	in Test

2018 PQP/Thresher – High Achievement Manufacturers

Manufacturers that tested a wide range of accelerated reliability indicators and demonstrated commitment to testing multiple products and changes to individual module family are, in alphabetical order: **Jinko Solar, Longi Green Energy Technology, Panasonic,** and **Solar Frontier.**



Summary

Background

RETC's PV Module Index is a summary of reliability and performance data with further evaluation of metrics that demonstrate a manufacturers commitment to quality. Results in this report represent data that was compiled during the 2018 calendar year. RETC plans on releasing annual PV Module Index reports with the 2020 edition being released in early 2020.

For the next 2020 edition, RETC expects various PQP/Thresher testing thresholds of duration and cycles to continue to increase, such as the thermal cycling test moving from 600 cycles of duration to 800 cycles. In addition, a more exhaustive characterization of a module family across the multitude of tests which demonstrate wider breadth or durability and robustness. Expectation is that downstream participants will want to see additional characterization done on LeTID (Light and Elevated Temperature Induced Degradation) which has shown to be a good barometer in testing PERC type cell technologies as well.

RETC is excited to publish this annual summary of results and is looking forward to working with its upstream module manufacturing partners and downstream (Project Developers, EPCs, Financial Institutions) players to incorporate feedback and identify where additional value can be created.

2018 Overall High Achievers

For this year's PV Module Index, RETC recognized 17 different suppliers and 40 awards for high achievement in various indicators and or categories. High achievement represents the top end of the distribution in terms of data generated. For the 'Overall' recognition, RETC analyzed data and demonstrated performance in all 3 categories for a given module family. Meaning did a particular module model perform well under Reliability characterization such as Damp Heat, Dynamic Mechanical Loading, and did that module also perform well in the Performance category of module efficiency, PAN file and LID as an example. Finally, the Quality category was evaluated in terms of a module's breadth of testing in PQP/Thresher environments, understanding of methodologies and efforts to characterize change control, and process controls across various factory locations.

The below matrix summarizes by manufacturer and specific model number the overall performance in these three key categories of Reliability, Performance, and Quality. Several modules did not receive specific testing at RETC, which does not indicate that they are not robust products, however, that RETC did not have specific data to make a determination on their performance.

Key:

High Achievement	In Test	Average Performance	No Data

2018 OVERALL RESULTS MATRIX

Manufacturer	Model	Reliability	Performance	Quality
A	A	High Achievement	High Achievement	High Achievement
B	B	High Achievement	High Achievement	High Achievement
A	C	High Achievement	High Achievement	High Achievement
C	D	High Achievement	Average Performance	High Achievement
A	E	In Test	High Achievement	High Achievement
D	F	High Achievement	Average Performance	High Achievement
A	G	High Achievement	Average Performance	High Achievement
C	H	High Achievement	Average Performance	High Achievement
B	I	High Achievement	No Data	High Achievement
E	J	Average Performance	Average Performance	In Test
E	K	Average Performance	Average Performance	In Test
F	L	No Data	High Achievement	No Data
G	M	No Data	High Achievement	No Data
H	N	No Data	High Achievement	No Data
I	0	In Test	In Test	No Data
J	P	In Test	In Test	No Data
K	Q	In Test	In Test	No Data
L	R	No Data	In Test	No Data
G	S	No Data	Average Performance	No Data
M	T	In Test	No Data	No Data
N	U	In Test	No Data	No Data
O	V	In Test	No Data	No Data

For 2018, two manufacturers are recognized for demonstrating high achievement across indicators in all three categories of Reliability, Performance, and Quality. RETC congratulates **Longi Green Energy Technology** and **Panasonic** for their respective performance in the 2019 edition of the PV Module Index.