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SunPower Maxeon Panel Technology 40-year Warranty Overview

Maxeon Solar Technologies White Paper

Contents

About Maxeon Solar Technologies

Maxeon Solar Technologies was launched as an independent company in 2020 following its spin-off from SunPower Corporation. The company continues to build upon a 35+ year foundation of solar technology innovation that began with the founding of SunPower Corporation in 1985.

Maxeon Solar Technologies designs, manufactures and sells SunPower brand solar panels in more than 100 countries around the world. Its flagship SunPower Maxeon solar panels reach record-setting efficiency and unmatched reliability[1], while its SunPower Performance solar panels offer reliability and output superior to standard solar panels. Maxeon Solar Technologies product lines are deployed at some of the highest-performing solar power plants around the world and are installed on residential and commercial rooftops by a global network of more than 1,200 trusted partners and distributors. MAXEON and SUNPOWER are registered trademarks in various jurisdictions. See **corp.maxeon.com/trademarks** for more information.

EXECUTIVE SUMMARY

Maxeon Solar Technologies has spent more than 35 years refining the patented cell and panel design of its SunPower Maxeon technology to maximize reliability and energy density. Both factors are key to lowering the levelized cost of energy (LCOE) of solar—as a longer, more productive panel life translates to higher energy output over the life of the system. While Maxeon Solar Technologies has previously published[i] information substantiating a 40-year useful life for its SunPower Maxeon Interdigitated Back Contact (IBC) solar panels in 2015, additional testing, modelling, and design enhancements now permit us to reinforce the panel's useful life with a comprehensive 40-year product and performance warranty.

> **NOTE**
> *Eligibility and terms for the SunPower Maxeon 40-year Warranty varies by market. Coverage beyond the standard 25-year warranty may require registration in applicable countries. Please contact your sales representative for full terms and conditions.*

The new SunPower Maxeon 40-year warranty is made possible through fundamental design differences which engineer failure modes out of the panel to deliver robust protection against environmental stresses. These design advantages are discussed further in the context of comparative experimental data below. In addition, Maxeon uses a physics-based model, PVLife, to estimate the expected performance impact over time from major degradation and failure modes. This model matches well with external field data and accelerated life testing, as published previously. Collectively, these data support a valid 40-year warranted life, as well as the notion that continued operation beyond this period is certainly feasible.

PROTECTING YOUR INVESTMENT IN SOLAR

Warranties provide a way for manufacturers to transfer the benefits of higher reliability and durability to their customers. Warranties are contractual, so they transcend marketing positioning and provide a foundation upon which customers can base financial returns—and for commercial and power plant solar projects, the warranty is a critical lever in determining project economics. Longer warranties provide assurances of more years of bankable income and energy production, with each additional year of coverage adding to a solar panel's value. Even for customers like sustainability-minded homeowners, who may not perform detailed financial analyses, longer warranties correspond to milestones like re-roofing their home or paying off their mortgage–or even just a desire to "*set it and forget it*". A more durable solar system negates the need for interim replacement of the system, while providing a longer-lasting impact on the environment.

Solar panel warranties are generally divided into a 'product warranty' which covers defects in materials and workmanship, and a 'power warranty' which ostensibly guarantees a percentage of nameplate power on an annual basis. However, many manufacturers may be exploiting a loophole between these two sets of warranty terms, pairing a shorter-term 10 to 15-year product warranty with a longer-term 25 to 30-year power warranty. As a result, it is not clear whether a product defect that causes power loss is covered beyond the product warranty term. For instance, if the electrical junction box falls off the rear of the panel, resulting in complete power loss—while clearly a manufacturing defect, would it be covered after the product warranty expires? It begs the question of whether a 12-year product warranty, paired with a 25-year power warranty, is effectively a 12-year combined product and power warranty.

To prevent any ambiguity in the interpretation of our warranty terms, Maxeon Solar Technologies was the first company to provide a combined 25-year product and power warranty. This decision in 2012 was based on the Maxeon cell's fundamentally unique back-contact architecture, track record of low claims, and proven manufacturing quality—the results of which were published[ii] for public review. In subsequent years, a handful of standard panel manufacturers followed Maxeon's lead by extending their combined warranties to 25 years. However, none have publicly disclosed the data to justify their warranty extension, making it unclear whether this move was simply a result of market pressure.

In the last decade, cost pressures have only intensified, providing the impetus for standard panel manufacturers to seek less expensive components. In addition, standard panel manufacturers are moving to new materials and technologies such as wire ribbons and heterojunction cells that lack a proven track record and independent validation of their reliability. Recent field studies are depicting power loss rates that exceed warranted levels[iii], with panels more recently placed into service actually showing higher rates of power loss compared to older panels[iii]. By contrast, Maxeon Solar Technologies continues to invest heavily in research and development, developing long-term supplier relationships, increasing its ability to model the physics of panel failure[i,iv,v], and validating performance in the field to *credibly* warrant the 40-year operation of SunPower Maxeon technology.

Considering solar is a long-term asset, combined with an increasing landscape of manufacturers rapidly developing new, potentially unproven technologies, customers not only need to critically evaluate their manufacturer's warranties, but their general quality and reliability track record as well. It's often up to the customer to challenge manufacturers on the true terms of their warranty and gain a comprehensive understanding of the data and field performance that justify the terms of the warranty, the restrictions that may negate warranty claims, and which party is responsible for addressing (and paying) for issues should they arise.

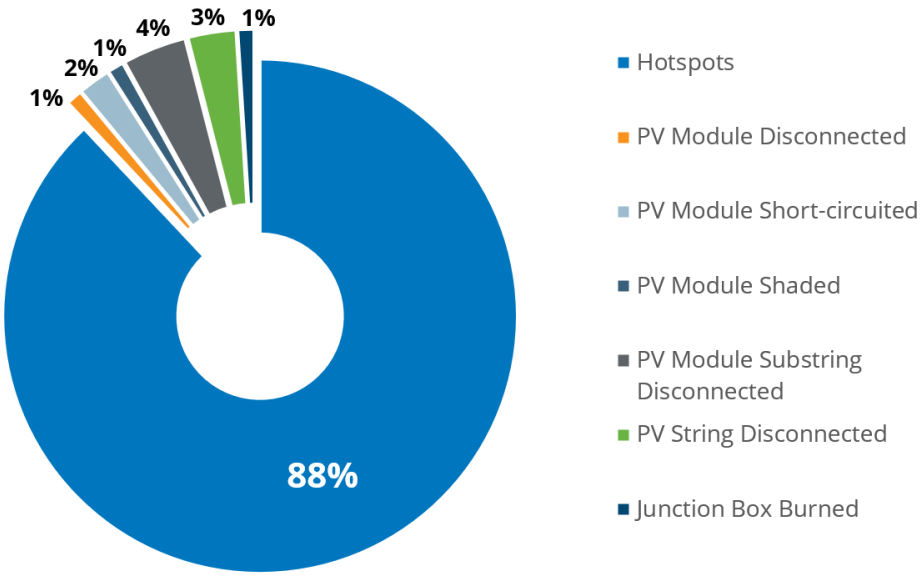
ENGINEERING A BETTER PANEL

In contrast to market trends, Maxeon Solar Technologies invests in a design ethos that is differentiated around long-term reliability and project value. SunPower Maxeon cell technology facilitates a longer panel life by designing out common failure modes, while leveraging superior energy density to deliver higher energy production over the life of the system.

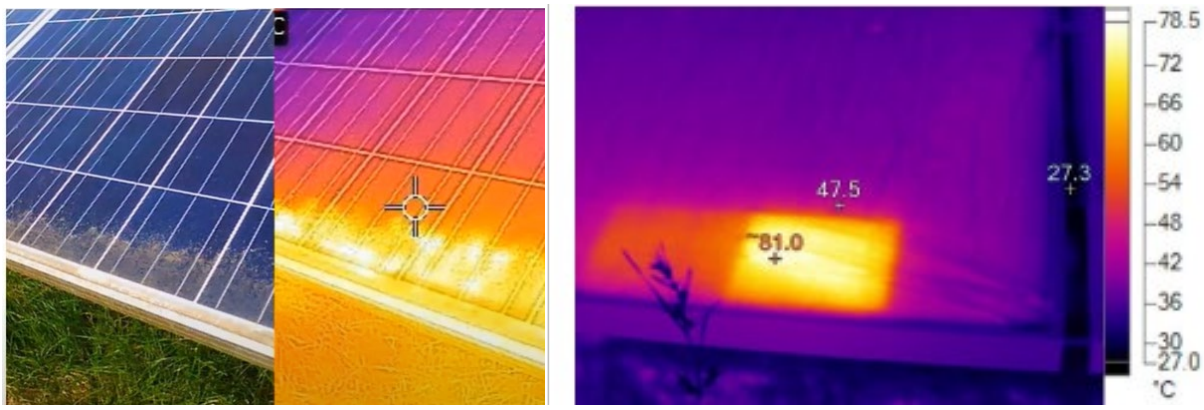
Shading and Severe Cell Cracking

Numerous studies[vi,vii,viii] point to hotspots and internal circuitry problems as the predominant issues affecting solar panel reliability. The results can be significant, including energy yield losses, inverter uptime issues, and even outright panel failure. These issues typically result from shading and cell cracking.

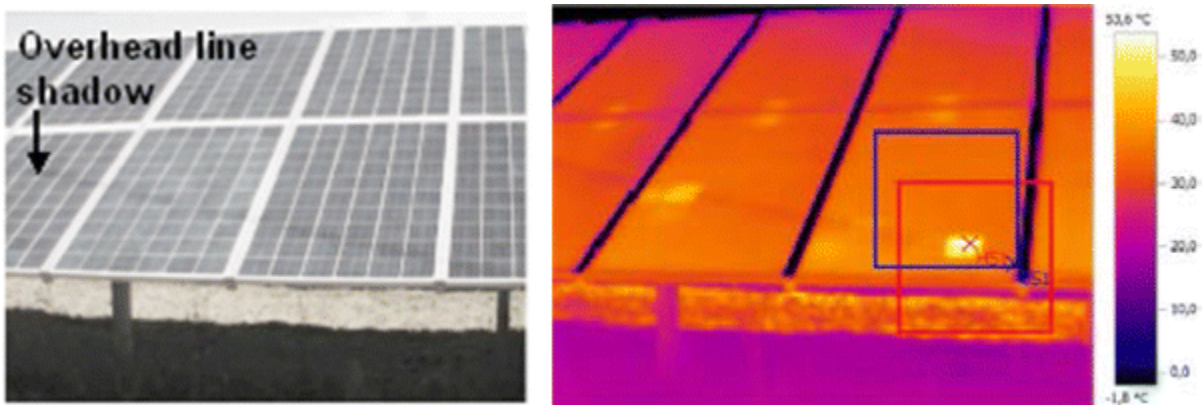
Shade occurs on a wide range of installations from sources including trees and roof structures on residential systems, inter-row shading on commercial systems, and soiling, which tends to affect all systems. Cell cracking can occur from transport, installation, wind and snow loading, and hail to name a few. Both types of issues cause cells to operate at high temperatures which can degrade surrounding materials and ultimately lead to panel failure.



PV Module issues based on IR inspections[ix].



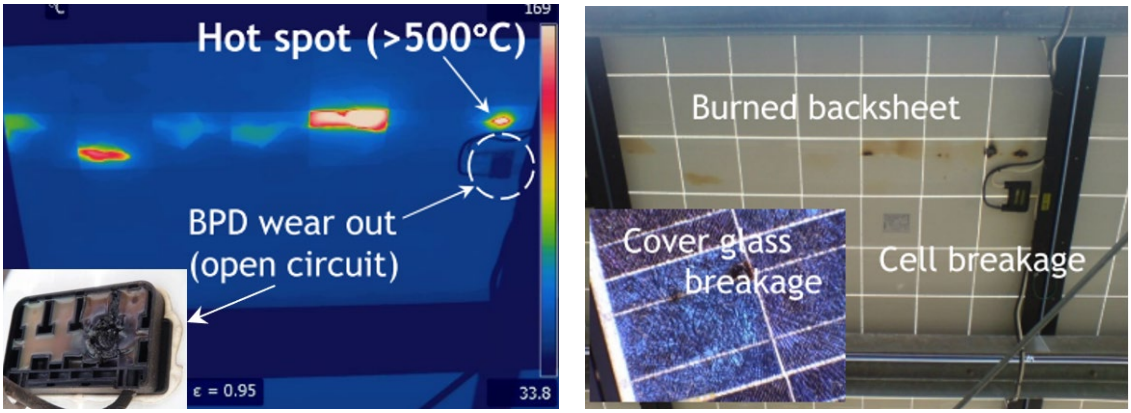
Examples of infrared scans showing the effects of partial shading from soiling[x] and plant growth[xi] on standard panel cell temperatures.



[xii] *elevating standard panel cell temperature.*

In more detail, a solar cell that is shaded or severely cracked does not produce the same electrical current as other cells in the panel. Electrically however, the affected cell is still driven to match the current of its neighbors and begins operating in reverse—converting power from neighboring cells into heat. In standard cells, this heating tends to occur in a concentrated area of the cell causing hotspots which feature temperatures high enough to degrade panel materials. To mitigate hotspot development, bypass diodes in the panel's junction box are employed to avoid, or bypass, sections of the panel containing affected cells.

However, when installed in the field, diodes allow some heating before they activate and, most importantly, they tend to wear out from repeated activation over time. Once a diode fails, heating in the panel will continue unmitigated, prematurely aging surrounding panel materials. The polymers used in panel construction degrade much faster as temperatures increase above 100°C, becoming embrittled or delaminated. Over time, this leads to damaged backsheets, deformed electrical circuitry, shattered glass, and subsequent system issues.

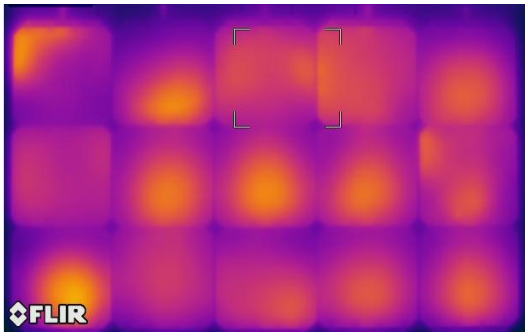


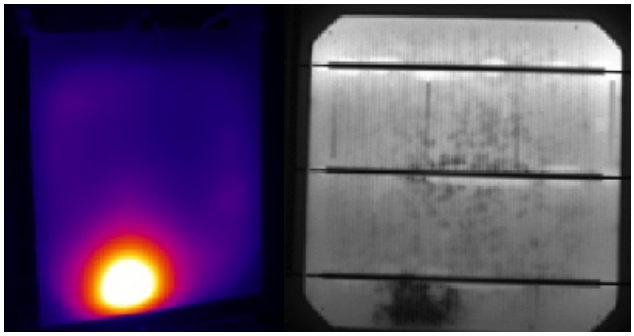
Hotspots found in the field showing bypass standard panel diode wear-out and resultant panel failure[xiii]

While diodes are tested during panel certification, these tests are intended to demonstrate a nominal level of build quality and out of the box safety, not long-term reliability. The certification test lasts only five hours—a panel experiencing daily intervals of shade can exceed that threshold within the first weeks of installation. A panel with a cracked cell that continually runs in reverse can exceed the five-hour test period in its first day of operation. Coincidentally, some standard panel warranties outright exclude coverage for panels exposed to shade.

Maxeon Solar Technologies has designed this failure mode out of its SunPower Maxeon panels through the unique patented properties of its IBC cell technology. A SunPower Maxeon cell running in reverse demonstrates lower heat generation that is relatively evenly spread across the entire cell, compared to the high heat found on standard cells in a very concentrated area. The power loss from a shaded SunPower Maxeon cell is low enough that several cells can run in reverse before a diode is required to activate, allowing panels to maintain higher energy yields even when shaded. As such, the diodes in SunPower Maxeon panels activate less frequently, increasing both energy production and useful life of the panel. If the diodes were to fail, SunPower Maxeon cells operating in reverse naturally run at safer temperatures, greatly extending the life of panel materials.

		Standard Solar Panels		
	Maxeon	**166mm**	**182mm**	**210mm**
String Current (A)	10.8	10.8	13.0	17.2
Approx Reverse Bias Voltage (V)	3.8	20	20	20
Heat energy to dissipate (W)	41	216	260	344
Heat dissipation pattern	Across cell area	Point hotspot		
Temperature change in shade (°C) versus panel temperature	40	>100[xiv]		
Temperature change in shade if diode is no longer protecting the panel (°C)	40	>150[xiii]		





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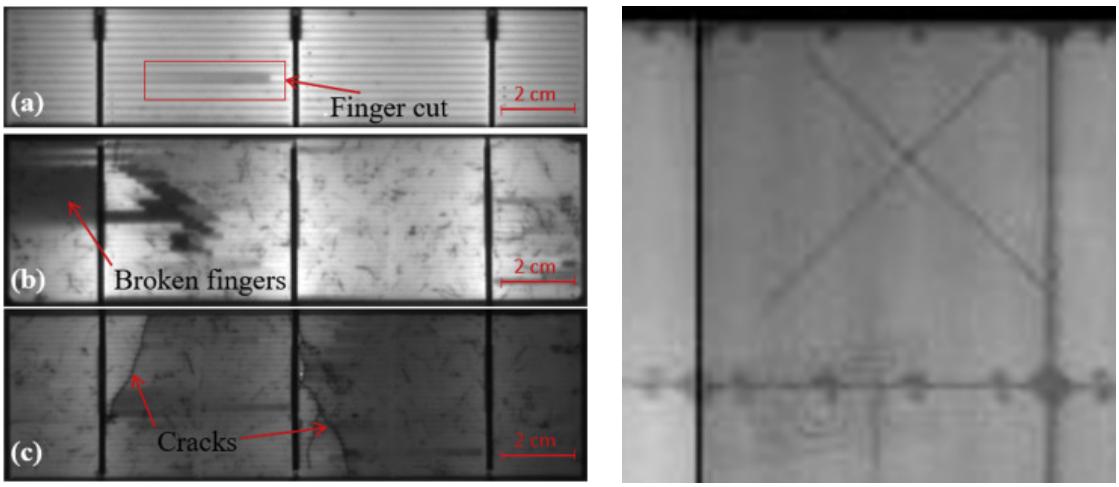
Cell Cracking and Thermal Stresses

As touched upon in the previous section, cracked cells in standard panels can occur from transport, installation, environmental stresses, and even poor manufacturing quality. These breaks in cell continuity can form 'dead zones' that prevent energy from leaving the affected portion of the cell. This failure mode is intrinsic to standard cells due to their architecture—a thin layer of silicon with screen-printed metal conductors and soldered metallic ribbons that lacks structural strength.

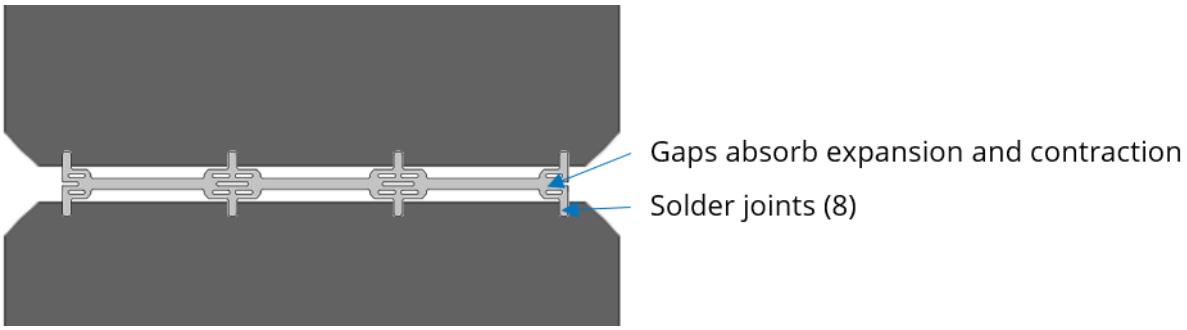
The conductive ribbons that run across the front and rear of the cells can be a source of additional power loss due to their thermal mismatch with the silicon. As temperatures rise and fall, the metallic ribbons expand and contract much more than the silicon, fatiguing the solder joints in the process. Over time, these stresses on the solder joints can cause them to separate from the cell, thereby concentrating the electrical current through a smaller solder contact area which ultimately increases cell temperature and induces hotspots. Additionally, constant thermal stresses can also cause the brittle conductive ribbons to sever, preventing the flow of electric current through the panel.



(Left) Electroluminescence scans showing sources of power and reliability loss from thermal cycling in standard cells.[xvi] (Right) Electroluminescence scans highlighting an imposed crack on a SunPower Maxeon cell resulting in no measurable power loss.

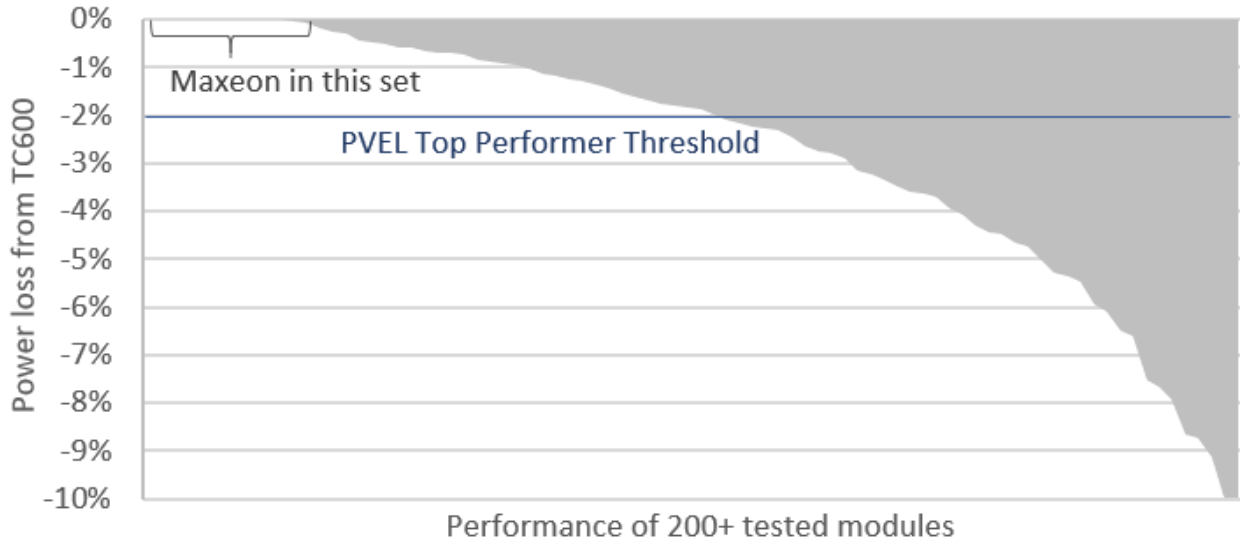
SunPower Maxeon IBC cells are designed with a solid metal foundation to retain continuity under thermal stresses and cracking by having near-continuous electrical connections throughout the entire cell. As cracks occur in the SunPower Maxeon cell, the affected silicon is not islanded. Extended thermal cycling tests have demonstrated long-term performance stability.

In addition to the metalization, Maxeon uses proprietary inter-cell interconnection tabs designed to mitigate fatigue from thermal expansion and contraction. First, SunPower Maxeon cells use a landed solder lead that runs the length of the cell and is much shorter than the conductive ribbons used in standard cells. Landed leads have been in use in the electronics industry for decades, and limit absolute movement in the connection, which means less fatigue over time. Second, the tabs have extra space which acts like the gaps in a bridge, providing room for the material to expand without imparting stress on the solder joints.



When SunPower Maxeon panels were evaluated as part of the PVEL PV Module Reliability Scorecard, these design differences delivered Top Performer results. While the PVEL test only goes to 600 cycles of

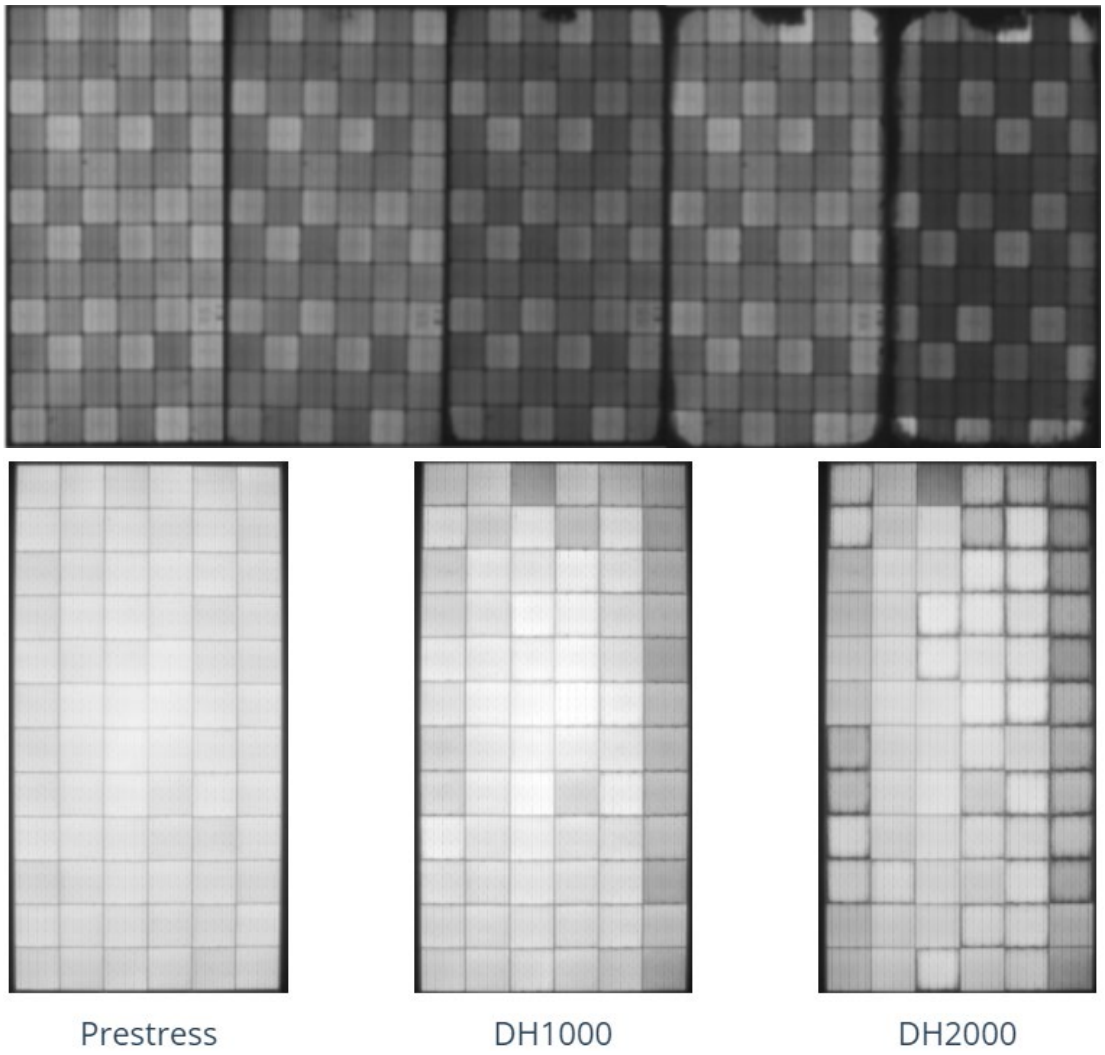
thermal cycling, SunPower Maxeon panels have previously exhibited stable long-term performance with less than 2% power loss beyond 2,400 thermal cycles to ensure a 40-year life[i].



Large set of comparative performance in thermal cycling testing from PVEL. SunPower Maxeon panels perform in the top echelon of the Top Performers.

Humidity and Corrosion

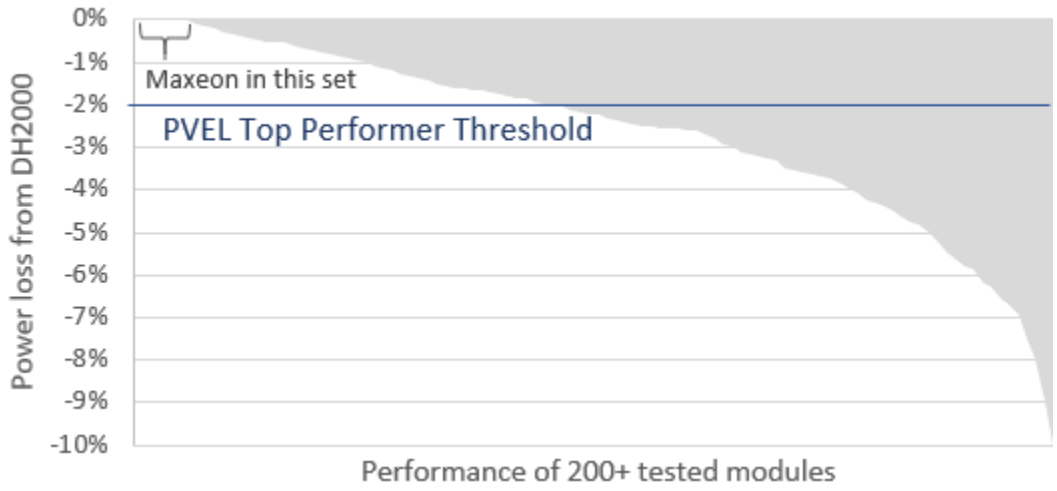
Another common failure mode in standard panels is caused by humidity-induced moisture entering the encapsulant (the polymers that hold the panel laminate together). In materials typically used in standard panels, moisture can diffuse from the environment into the panel where it reacts with the encapsulant polymers to form acetic acid. This acid oxidizes the screen-printed silver from the cells, taking away their ability to conduct electricity, and causing permanent power loss.



Examples of electroluminescence scans showing the effects of damp heat stress oxidizing metal lines from the front of standard panel cells, as well as delamination [xvii] [xviii]

Again, Maxeon Solar Technologies has designed out this failure mode through two approaches. The first is by using metals that are not prone to corrosion on the cell. Second, SunPower Maxeon panels use an engineered encapsulant which is severely hydrophobic such that moisture does not readily diffuse into the laminate.

In the same PVEL PV Module Reliability Scorecard discussed above, these design differences again delivered Top Performer results. While the PVEL test only goes to 2,000 hours of damp heat, SunPower Maxeon panels have previously exhibited stable long-term performance with less than 2% power loss beyond 7,500 hours to ensure a 40-year life[i].



Large set of comparative performance in damp heat testing from PVEL. SunPower Maxeon panels perform in the top echelon of the Top Performers.

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Additional Benefits of SunPower Maxeon Longevity

While SunPower Maxeon IBC panels feature several intrinsic reliability advantages that contribute to its 40-year warranted life, the story doesn't end there. SunPower Maxeon panels also leverage greater energy density and an innovative sustainability profile to generate more value for customers over the course of the 40-year warranty.

***Energy Density*:** SunPower Maxeon panels deliver significantly more energy per square meter (*energy density*) than standard panels due to their higher efficiency (*watts per square meter*) and higher energy yield (*kWh generated per rated watt*).

With the industry's leading commercially available efficiency, SunPower Maxeon IBC panels offer more installed watts per square meter. This is primarily accomplished through the use of high-grade n-type silicon, lower internal resistance, and an absence of ribbons on the front of the cell. These design features combine to enable cells to not only generate more electrons but convert a higher percentage of them to energy. Compared to a standard 20.5% efficient PERC panel, a 22.7% SunPower Maxeon panel powers 11% more watts per square meter. Higher efficiency panels permit customers more flexibility to design their systems, as they are not required to utilize all available space on their roof. This has the added benefit of leaving space for future system expansion should energy needs grow, such as from a transition to electric vehicles. Additionally, the higher efficiency of the SunPower Maxeon panel lowers installation costs by requiring less materials (e.g. panels, racking) and labor hours for the same number of watts installed as a system featuring standard panel technology.

SunPower Maxeon panels also generate higher yield, which means more kWh are generated for each

watt installed. Even though all panels are tested under 'Standard Test Conditions' (STC), which measures their wattage, the amount of energy generated per watt can vary once the panels are installed on a roof. STC is an idealized scenario to make testing easier—the panel is tested at room temperature with an ideal amount of light and solar spectrum. However, panels often experience much hotter operating temperatures on a roof, with variable amounts of light and a constantly varying 'color' of light due to clouds and time of day. In energy modelling using third-party measurements and independent testing, SunPower Maxeon panels demonstrate 5%[xix] more energy per rated watt (Kwh/W_{DC}) in real-world conditions. Additionally, their performance under shade provides an additional benefit that is not typically considered in energy modelling or external tests. In studies where panels are intentionally shaded, SunPower Maxeon panels can produce as much as 30%[xx] more energy per watt over standard panels.

Efficiency and energy yield combine virtuously, with 11% higher power density and 5% higher energy yield, a Maxeon panel delivers 17% higher energy density than standard panels.

***Sustainability*:** SunPower Maxeon panels permit customers to meet their energy goals sustainably. While the ethics of sustainable practices are important, panels made with a strong sustainability profile can lower customer risk of future regulatory changes, as well as lower end-of-life decommissioning costs. SunPower Maxeon panels are ROHS and REACH certified, do not use fluorinated backsheets, are Declare™ compliant, and are Cradle-to-Cradle Bronze certified which can contribute to green building credits. Maxeon panels also use no forced labor and a 'clean' supply chain—from initial polysilicon to panel production, this avoids ethical concerns as well as practical issues around importation. A longer warranted life means that there is significantly more energy created from each panel, while extending the sustainability footprint of the technology. Additional details surrounding Maxeon Solar Technologies' sustainability practices can be found in our inaugural Sustainability Report[xxi].

VALIDATING 40-YEAR WARRANTY COVERAGE

While anyone can arbitrarily write their desired warranty terms into policy, Maxeon Solar Technologies works to extensively test and qualify its products to ensure they truly meet their warranty terms.

Starting with the design process, Maxeon Solar Technologies uses PVLife, a tool which uses physics-based models, very long duration chamber testing, and calibration to field data to quantify the impact of design updates. PVLife has been presented[iv,v] at several conferences and has been validated against large-scale performance of fielded systems[xxii]. Through the PVLife program, SunPower Maxeon panels have undergone very long duration testing to ensure understanding of the long-term impacts of environmental stresses. For example, Maxeon Solar Technologies has conducted thermal cycling of beyond 2,000 cycles, 10 times longer than IEC requirements, to ensure that the constant temperature changes on a roof do not impact electrical connections; damp heat/humidity testing beyond 7,000

hours, 7 times the IEC requirements, to ensure robustness in hot and humid climates; and combined high mechanical load and humidity freeze testing beyond 350 cycles, 35 times IEC requirements, to ensure long-term stability even if cells are severely cracked.

In addition, Maxeon Solar Technologies participates in external validation with respected industry thought leaders. For example, Maxeon has had panels monitored at the National Renewable Energy Laboratory (NREL) for over ten years, where they've shown nearly zero degradation[xxiii]. Maxeon also participates in PVEL's PV Module Reliability Scorecard, with SunPower Maxeon IBC panels yielding a 'Top Performer' result in recent reliability tests.

Field performance is critical to validate chamber testing, and Maxeon conducted a study with NREL and DNV surveying hundreds of megawatts of solar plants which showed a degradation rate of 0.2% per year for SunPower Maxeon panels, well below their warranted 0.25% degradation rate[xxii]. The same study showed standard panel degradation of 0.7%, much higher than the warranted degradation rates of many manufacturers.

Ultimately, these internal and external analyses have provided confirmation of the stable linear performance and degradation of SunPower Maxeon solar panels—well below their warranted power degradation rate. The evidence outlined in this report provides Maxeon Solar Technologies with full confidence that our SunPower Maxeon IBC panels will meet the terms of their 40-year warranty, while continuing to deliver energy beyond a 40-year warranted life.

To learn more about SunPower Maxeon technology, contact your local sales representative, or visit **sunpower.maxeon.com**

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MAKER OF SUNPOWER PANELS

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