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SunPower Performance Panel Technology for Large-scale Installations

Maxeon Solar Technologies

SunPower Performance Technology White Paper – February 2021

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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 conventional 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 1,100 trusted partners and distributors.

Introduction

The shingled cell SunPower Performance solar panel combines 35+ years of materials and manufacturing expertise with conventional p-type mono PERC cells to surpass the performance, reliability and aesthetics of conventional panels.

The Performance panel originated from SunPower Corporation's 2015 acquisition of Silicon Valley-based, Cogenra Solar. Cogenra's innovative approach to stringing solar cells paved the way for the Performance panel by eliminating key vulnerabilities in conventional panel cell connections.

Since 2015, more than 4 GW of high reliability SunPower Performance panels have been deployed across 60+ countries, making it the leading shingle cell technology on the market today.[2]

In 2020, SunPower Performance 3 panels were introduced to the market, incorporating a dedicated panel for large-scale power plant installations (UPP). This new form factor complemented existing models that catered to residential (BLK) and commercial (COM) installations (figure 1).

Figure 1: A historical look at the evolution of the SunPower Performance panel line.

Most recently, Maxeon Solar Technologies introduced the SunPower Performance 5 panel for large-scale installations and solar power plants (figure 2). The Performance 5 maximises power density with larger format G12 (210 mm) cells and bifacial energy capture. This latest generation of SunPower Performance technology further builds on the proven design of earlier generation panels by using a framed glass/glass construction for enhanced strength and durability that can extend panel life.

As the industry transitions to larger, higher power panels such as the Performance 5, its ability to reduce the cost structure of solar power plants greatly improves. With higher power density comes reductions in land, balance of system (BOS) hardware, and labour—all of which drive down the levelised cost of energy (LCOE) of today's large-scale installations.

The SunPower Performance 5 is designed to work optimally with currently available BOS products, including trackers, inverters and DC hardware. In addition, the Performance 5 allows for simple design changes at the factory to better align voltage and current with future BOS product offerings.

The SunPower Performance 5 panel capitalises on the insights and experience gained from developing, designing, building and operating more than 5 GW of power plants with SunPower technology across six continents. That knowledge has been instrumental in developing the latest generation of SunPower Performance panels to deliver the production, reliability and durability for today's power plant EPCs and developers.

SUNPOWER | PERFORMANCE 5

Key Features
Full square G12 cells
Bifacial power generation
Framed glass/glass construction

Product Warranty	12 Yrs
Power Warranty	30 Yrs
Yr 1 Warranted Power Output	98.0%
Maximum Annual Degradation	0.45%
Yr 30 Warranted Power Output	85.0%

Note: 25-year product and power warranty option also available

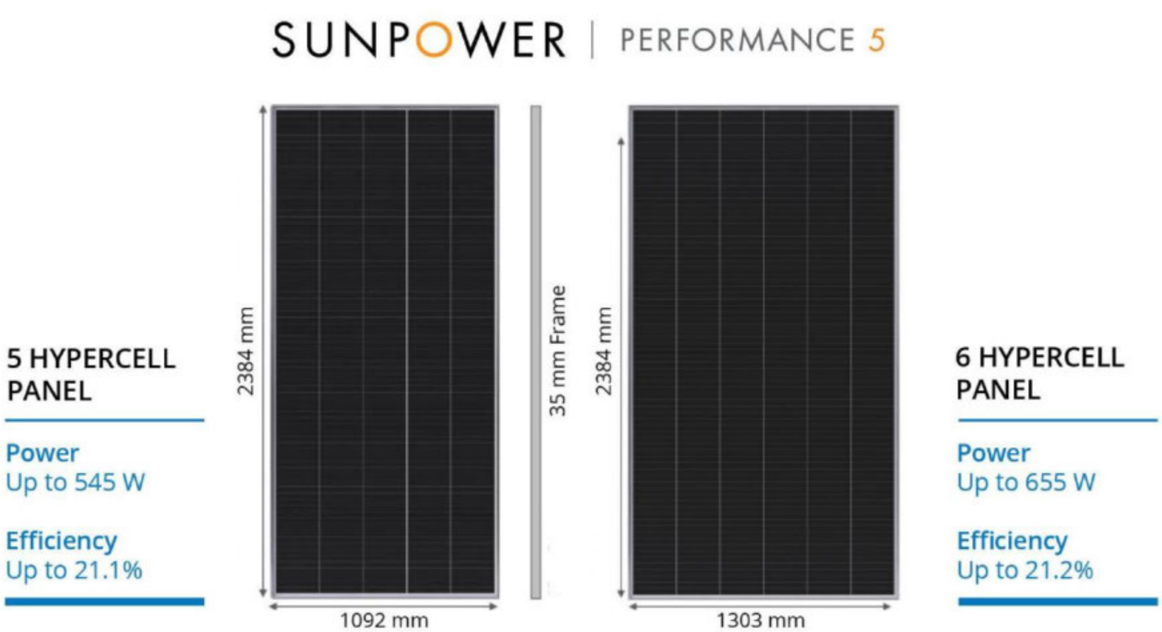

Figure 2: SunPower Performance 5 panels for large-scale installations.

SunPower Performance Panel Core Technology Advantages

The shingled layout, or hypercell, forms the unique and innovative backbone behind each SunPower Performance panel. From its durable electrically conductive adhesive (ECA), to its redundant cell connections, Performance panels offer a variety of production, durability and reliability advantages over conventional panels.

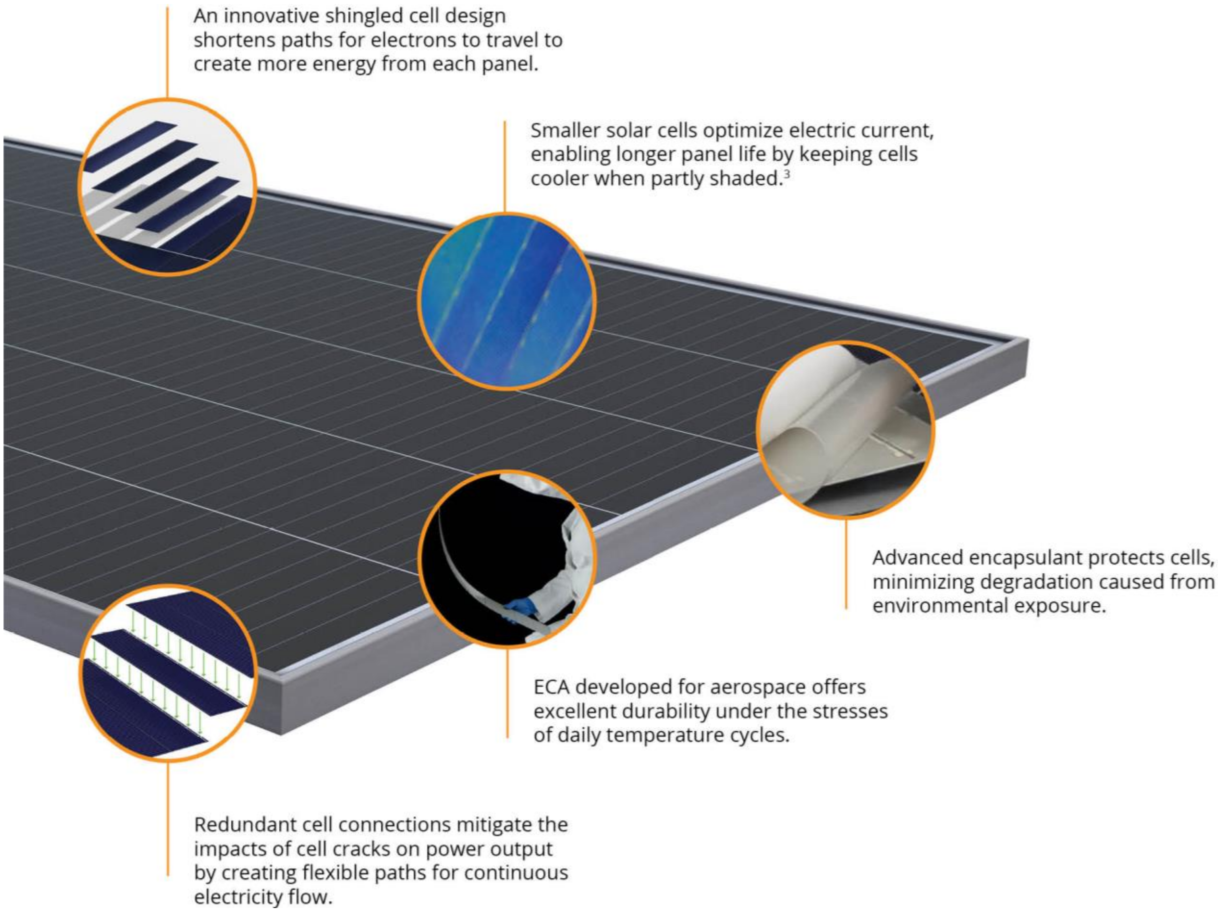

Figure 3: SunPower Performance panels are uniquely engineered for more lifetime energy, greater reliability and better durability over traditional front contact panels.

Electrically conductive adhesive maximises panel durability

The SunPower Performance panel eliminates the use of soldered cell connections—designing out one of the major failure modes of conventional cells (figure 4). These metallic connections expand and contract as temperatures rise during the day, and cool at night. This repeated daily stress can cause solder bonds to break and cells to crack. With cracked cells no longer functioning properly, bypass diodes are activated, limiting the amount of power the panel can produce. If the diode fails from continued activation, current will then be forced through the defective cells and ultimately lead to hotspot formation and permanent power loss.

In place of these fragile solder bonds, the SunPower Performance panel uses an advanced electrically conductive adhesive (ECA) originally developed in the aerospace industry. The ECA provides a robust solution with high electrical conductivity. It has the ability to adhere to diverse materials, bonding the edge of the front of one cell to the rear edge of the next cell. This innovative approach increases the number of cell-to-cell contact points, while reinforcing each connection to withstand the stresses of daily temperature swings and corrosion over time—while removing toxic lead from the interconnection.

A recent study of site inspection results from Dupont demonstrated that the predominant panel failure mode was attributed to the weakness of the cell-ribbon bond on conventional panels (figure 5).[4] Eliminating these connections has been a critical factor in the low claim rate of SunPower Performance panels—less than 50 failures per million panels installed globally.[5] In addition, the glass-glass architecture of the SunPower Performance 5 panel further strengthens its resiliency in the field.

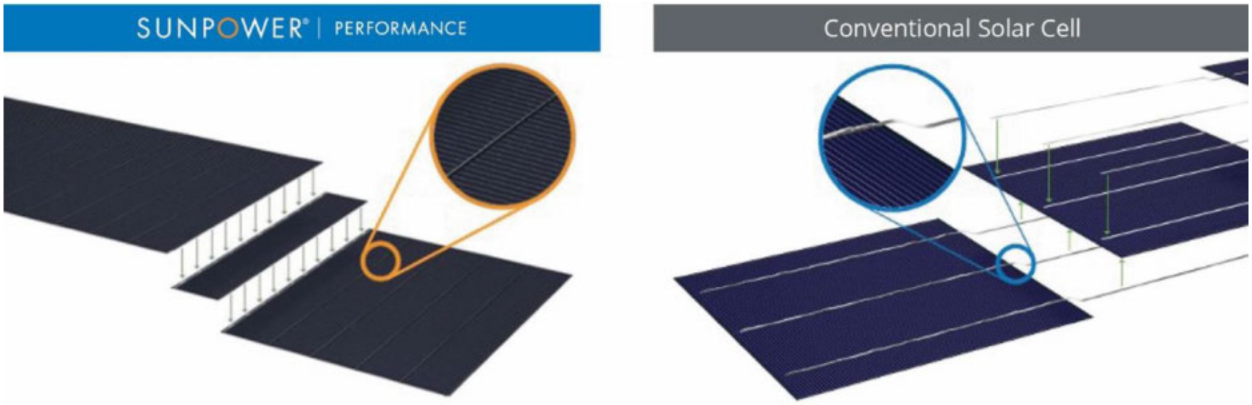

Figure 4: SunPower Performance panels eliminate the use of soldered cell connections–designing out one of the major failure modes of traditional cells.

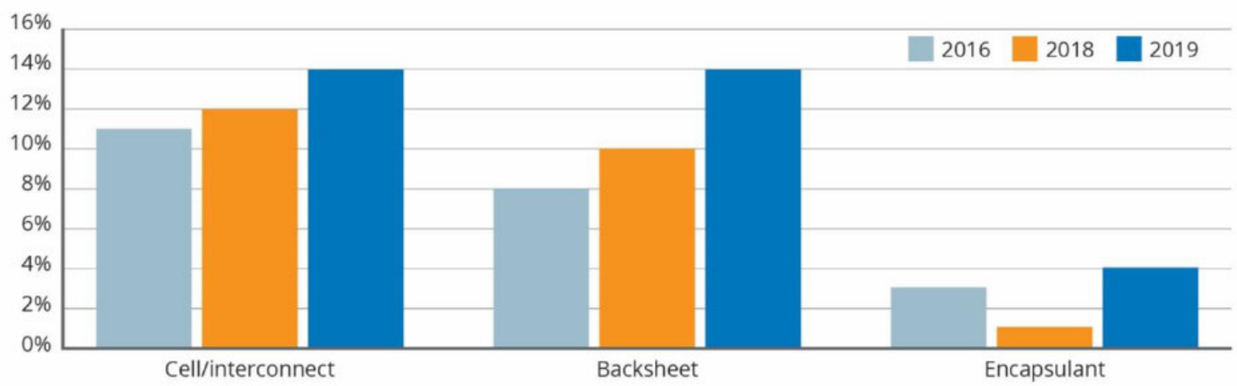

Figure 5: Inspection results from Dupont's Global PV Reliability Field Analysis featuring key causes of panel failure amongst recently installed conventional panels.

Redundant cell connections keep current flowing

SunPower Performance panels mitigate the impacts of cell cracks on power output by creating flexible paths for continuous electricity flow. The approach ensures there is no single point of failure throughout the panel (figure 6). In a conventional cell, cracks can propagate until reaching another crack or the ribbon of the cell. As cracks form throughout the cell, they inhibit the flow of current to the conductive ribbons. In the case of the shingled cell Performance panel, the shorter cell length limits the propagation of cracks, isolating cracks to a smaller area of the cell. The highly redundant ECA connections act as a "mesh" to maintain current flow.

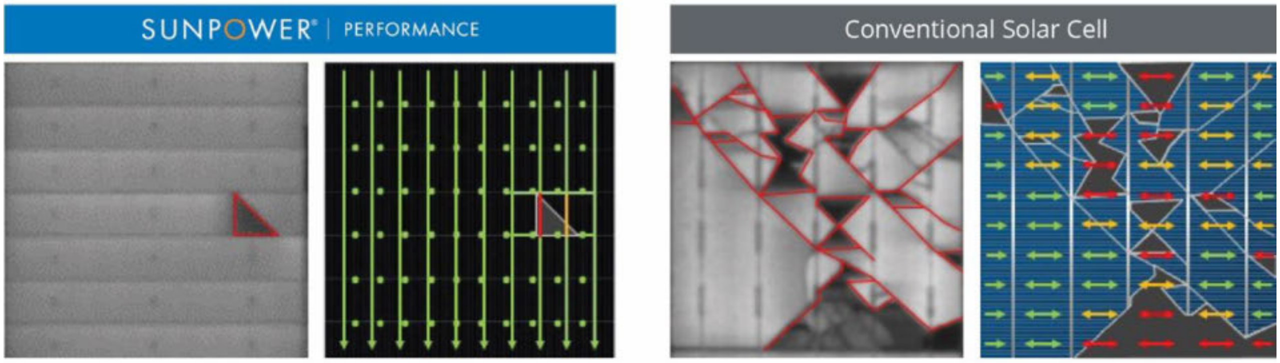

Figure 6: Not only are the smaller cells of the SunPower Performance panel less susceptible to breakage, but they confine cracks to a smaller portion of the panel, while maximising energy generation through a series of redundant electrical connections.

Parallel circuitry mitigates the effects of shading and soiling

Landscape orientation (panel)

The unique parallel cell architecture (hypercell) of the SunPower Performance panel ensures optimal performance against shading in landscape-orientation (figure 7). When the bottom of the panel encounters inter-row shade or soiling, the panel loses power in proportion to the amount of shade covering the hypercell. In a scenario where an entire hypercell of a 5-hypercell panel is shaded, only 1/5 of panel power is lost, without activation of the bypass diodes.

In comparison, current flows through conventional panels in a continuous, serial circuit. Any obstruction to this flow, can have detrimental effects on panel operation. Therefore, the panel is typically partitioned into three distinct electrical zones, allowing the panel to bypass obstructions to energy flow should one occur. A linear shadow cast along the bottom of the conventional panel forces one of the bypass diodes to activate, resulting in a 33% power loss.

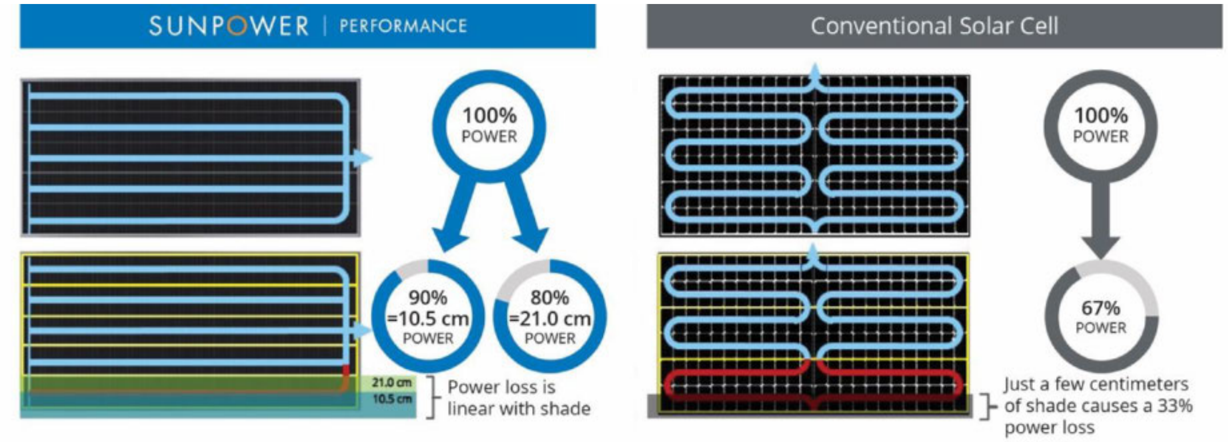

Figure 7: The parallel cell architecture of the SunPower Performance panel minimises power loss from shading and soiling in landscape orientation.

Portrait orientation (panel)

Should the SunPower Performance panel be installed in a portrait orientation, its shading performance still surpasses that of conventional panels (figure 8). The bypass diodes of the Performance panel are arranged horizontally. When the bottom row cells are shaded in portrait orientation, one of the bypass diodes will activate. In this situation, energy flow is re-routed through the top 2/3 of the panel, resulting in a 33% power loss. For this reason it is recommended that Performance panels be installed in landscape orientation where possible to maximise energy output.

For conventional panels positioned in portrait orientation, the bypass diodes split the panel in half. Shading the bottom portion of the conventional panel will result in 50% power loss.

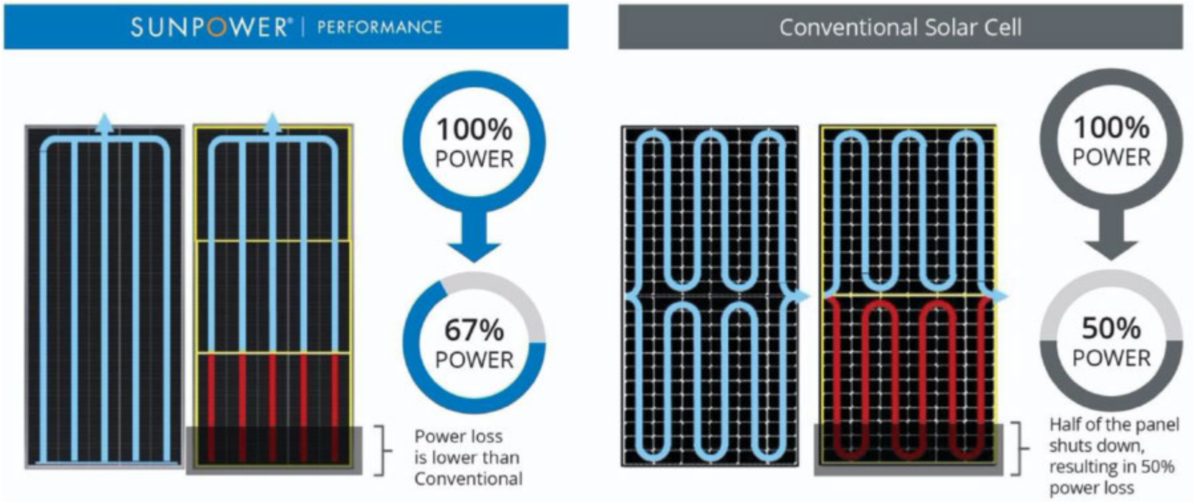

Figure 8: The SunPower Performance panel outperforms conventional panels when shaded in portrait orientation.

Landscape orientation (string)

When a string of SunPower Performance panels in landscape orientation encounters linear shading across the tracker row, the voltage of the panel remains unchanged (figure 9). This allows inverters to continue operating in their optimal window and maintain peak efficiency.

With the bypass diode activated in the conventional panel, the string operates in a similar fashion, but power is further limited by the electrical configuration of the panel.

Figure 9: The SunPower Performance panel maintains its advantage in shade when consistent linear shadows (i.e. row-to-row shading) impact the entire tracker row in landscape orientation.

Portrait orientation (string)

When a string of SunPower Performance panels is in portrait orientation with linear shading across the tracker row, only 1/3 of each panel is bypassed (figure 10). String power is reduced, but the advantage of the diode configuration allows production to continue. In the case of the conventional panel, the string will continue to operate at 50% power.

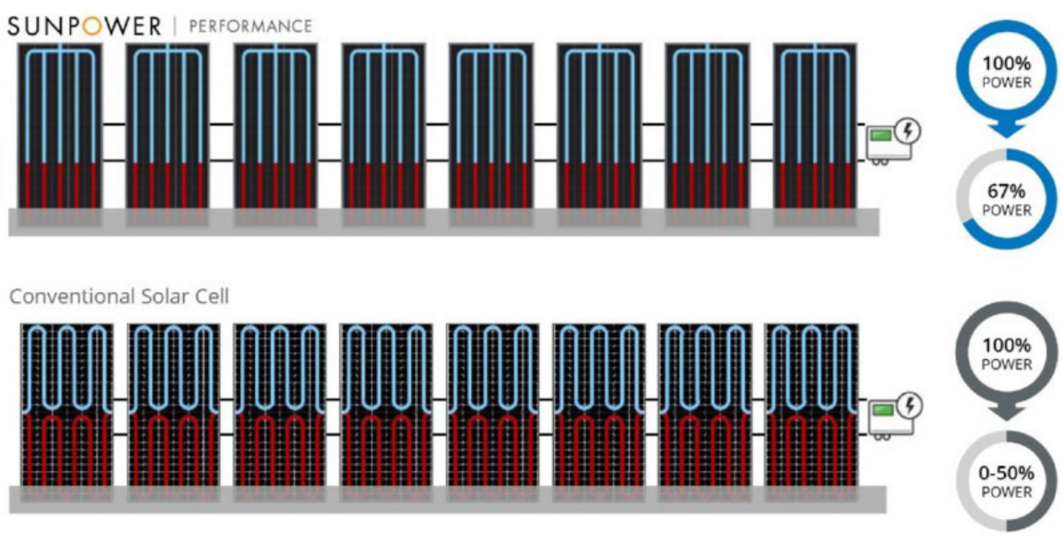

Figure 10: The SunPower Performance panel produces more energy than conventional panels when a consistent linear shadow is cast across the entire tracker row in portrait orientation.

Backside shading

The design of the racking system—the quantity, placement, and size of rails—is a common source of rear-side shading in bifacial panels. Albedo is the primary factor that impacts bifacial gain. Based on experiments run at SunPower Corporation's Davis, California R&D lab, it was shown that while a higher albedo does produce higher bifacial gain, the rear irradiance shading impact increases as well.[6] This can cause rear side shading of certain tracker elements to increase due to a larger difference in irradiation between rear-side areas without shade versus those shaded by the racking system. As the albedo decreases, the shading impact on bifacial gain becomes insignificant. Once again, as with front-side shading, the unique parallel circuitry architecture of the SunPower Performance panel minimises the impact of shading. It is suggested that developers contact their tracker OEM for additional information.

Electrical architecture dissipates effects of hotspots

Cell cracks, shading and soiling increase stress on the panel, and can lead to encapsulant browning, backsheet embrittlement, diode failure, and most importantly, hotspots. While hotspots initially reduce panel output, they represent a significant reliability risk to long-term system operation.

Hotspots occur when a portion of a panel, usually a single cell or a spot on a cell, has reduced performance and no longer produces enough current to match neighbouring cells. The solar cell then operates in reverse, consuming power from its neighbours and converting it to heat. The weakest spot on the cell becomes a resistive load, and the cell temperature increases. This effect can be caused by a single event, such as a cell crack, or by regular events such as daily shadows from nearby objects.

In a conventional panel, all of the current must go through the affected cell. The heat dissipation in the weak cell, or hotspot, can be described by $P = I * V$ where the current (I_{sc}) of the panel is available, often as much as 11-18A in panels using larger 182mm and 210mm cells. In the case of panels using larger wafers and full cells, the higher cell current increases the heat dissipation. Slicing the cell in half, reduces the current by half—while slicing the cell into smaller strips, such as the SunPower Performance panel, further decreases current.

Independent research has shown that hotspot temperatures are positively correlated with the panel current, meaning higher current panels generate higher hotspot temperatures.[7] As larger cells enter the market, it is becoming imperative that manufacturers adopt some form of cell slicing to mitigate the impact of hotspots. In the case of a full cell panel with a current of 13A and negative bias of 15V, the cell could generate upwards of 195W of heat energy from a single hotspot, which can translate into temperatures well above 150 °C, enough to cause permanent damage to the encapsulant and backsheet. It's worth noting here that some panel manufacturers are beginning to include exclusions in their warranties for panels affected by shading.

Bypass diodes are generally employed to avoid hotspots. As cells go into reverse bias, the substring can be effectively shut down to avoid overheating. However, if cells experience routine shade, soiling or cell cracks, then the cells are consistently pushed into reverse bias which can accelerate diode failure. While IEC 61215 testing does address diode performance, the relatively short time frame of testing limits insights into the long-term viability of these components. Many solar panels are generally expected to last decades in the field, and that can be a lot to ask of a diode constantly under stress. A field study conducted in 2012, found that for panels over 10 years old, approximately 20% of the diodes had completely failed.[8]

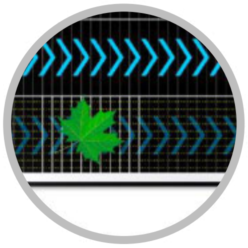

Figure 11: The independent SunPower Performance hypercells, backed by redundant connections, offer more tolerance against spot shadows.

When the cells of the SunPower Performance panel are shaded or cracked, the current will take the path of least resistance and be shared by the neighbouring cells (figure 11). The current in any one string is a portion of the operating current of a full cell, greatly reducing the threshold for power dissipation (I * V). As a further mitigating measure, the structure of the Performance panel puts the affected cell in direct physical contact to its neighbouring cells which helps to dissipate hotspot heat. With a lower hotspot temperature in the cell, energy loss is minimised. In a conventional panel, cells are only connected by ribbons, which have little heat transfer capability. Under severe cell cracking or worst-case shading conditions of conventional cells, SunPower Performance panels operate at 40-50 °C lower temperature (figure 12).[9]

While SunPower Performance panels are passively safe, bypass diodes are embedded in their junction boxes to increase energy yield under partial shading should they be required.

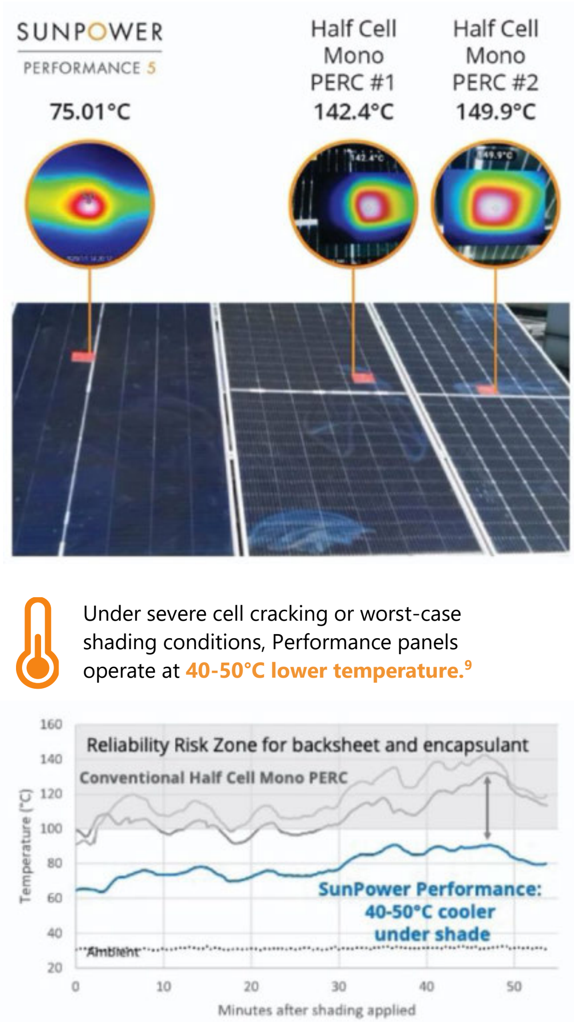

Figure 12: SunPower Performance panels reduce the risk of temperature-related failures through crack mitigation and unique circuitry.

LeTID/LID-resistant wafers increase panel power in real-world operation

Doping is an important process in wafer manufacturing. Most cells throughout the industry utilise some form of doping to achieve p-type properties in their silicon. Earlier generations of SunPower Performance panels used boron-doped silicon, which has been known to be susceptible to light induced degradation (LID). However, SunPower Performance 5 panels use an enhanced doping process with LID-resistant wafers to virtually eliminate the effects of LID.

SunPower Performance panels with cells from the LID-resistant wafers were sent to Fraunhofer CSE for independent LID and LeTID (light and elevated temperature induced degradation) testing (figure 13). The final report delivered from Fraunhofer CSE states:

- *Power changes during LID testing are negligible (50 °C, 1000 W/m², 15 kWh/m², IEC 61215 MQT 19)*
- *In the LeTID test scenario (75 °C, 1 A, 702 h) no degradation of panel power (< 1 %) is observed*
- *The tested panels are stable regarding LID and LeTID*

Given continued fleet monitoring and extended testing results, SunPower Performance 5 panels offer a minimum warranted power output of 98.0% in their first year of operation, with a maximum annual degradation rate of 0.45% over 30 years.

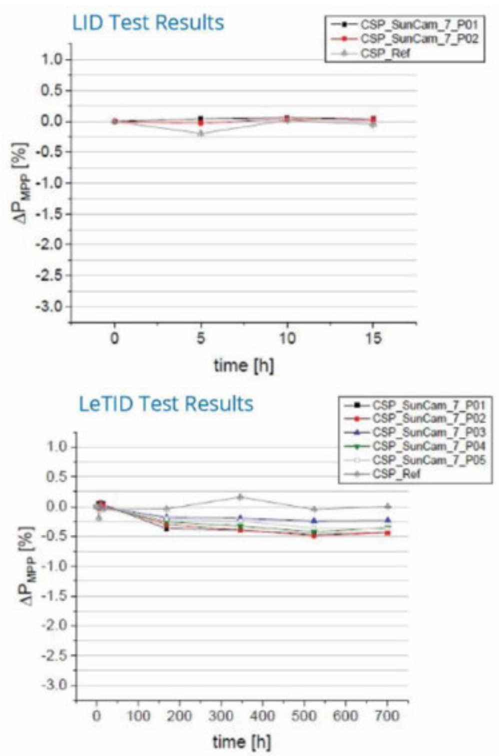

Figure 13: Fraunhofer LID and LeTID test results for SunPower Performance panels.

Lower temperature coefficient improves yield in higher temperatures

The temperature of a solar panel has a direct effect on its ability to generate electricity. This has to do with the laws of thermodynamics and how heat limits the ability of electronics to produce power. As a panel heats up, power output is reduced. This relative change in the panel related to temperature increase is called its temperature coefficient. The temperature coefficient is expressed as the percentage decrease in power output for every 1-degree Celsius (°C) increase in temperature beyond 25 °C. Improving the temperature coefficient of the panel will decrease the power loss experienced from higher temperatures.

SunPower Performance panels have a temperature coefficient of -0.34 %/°C, which is validated by the independent PV Evolution Laboratory. This means that for every 1 °C above 25 °C, SunPower Performance panels decrease in relative efficiency only by 0.34 %/°C.

This is a significant advantage for SunPower Performance panels in comparison to conventional panels that exhibit temperature coefficients in the range of 0.36% - 0.37% W/°C.

When comparing the performance of two panels in a hot climate where the operating temperature could reach 60 °C, the lower temperature coefficient of the SunPower Performance panel offers a 1.1% advantage over the conventional panel. In a 500W panel, this translates to an additional 5.5W of power per panel.

	°C above STC	Temperature Coefficient	Efficiency Loss
Performance Panels	35 °C	-0.34%	-11.9%
Conventional Panels	35 °C	-0.37%	-13%

A Better Panel. A Better Warranty.

The data presented throughout this paper is intended to clearly demonstrate that SunPower Performance panels are designed for greater reliability over time. This laser-focus on reliability underscores the bankability of SunPower panel technology. SunPower technology has been recognised by the industry's most renowned advisors and has led to Total S.A., the world's 4th largest public energy company, becoming its lead investor.[10]

Each SunPower Performance panel is manufactured with the absolute confidence to deliver more energy and reliability over time. The SunPower Performance panel delivers long-term results, backed by a stronger warranty than conventional solar (figure 14). Over the course of its 30-year power warranty, the SunPower Performance 5 is warranted to deliver more power than conventional panels (figure 15). As noted previously, a 25-year product and power warranty option is also available—enquire with your sales representative for additional information.

In addition, SunPower Performance panels are designed to last beyond their warranty. The expected lifetime, or 'useful' life, of a solar installation is defined as the time when 1% of total panels have dropped below 70% power output. This definition is used to ensure that a site will continue to generate useful revenue without incurring significant maintenance or large panel current mismatch. Earlier versions of SunPower Performance panels, which share the same electrical architecture of the Performance 5 bifacial panel, have undergone a third-party review with Leidos. Leidos found that the use of identical encapsulant and backsheet from SunPower Maxeon interdigitated back contact panels in conjunction with a low-stress cell interconnection reasonably infers an expectation of a more than 35-year useful life for SunPower Performance panels.[13]

	SunPower Performance 5 Panel Warranty	Conventional Solar Panel Warranties[11]
Product		
Panel	12 Years	12 Years
Power		
Year 0	98.0%	97.5%
Yearly decline	0.45%	0.55%
Year 25	87.2%	84.3%
Year 30	85.0%	N/A

Figure 14: SunPower Performance 5 warranty coverage compared to representative standard efficiency solar manufacturers.

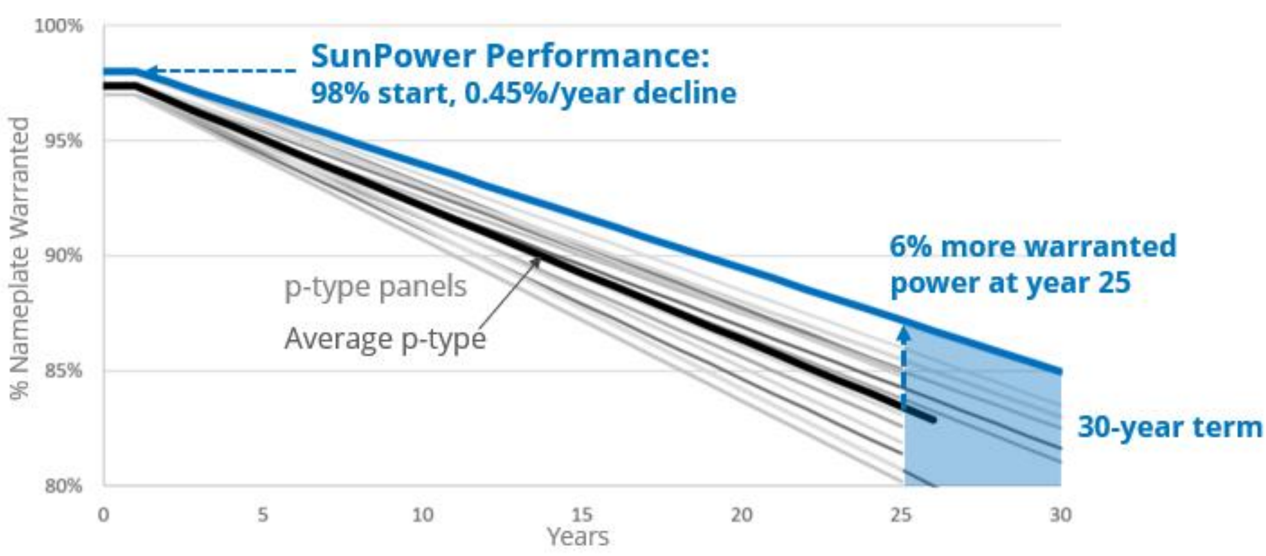

Figure 15: SunPower Performance panels offer a high-power warranty, for more bankable power every year. [12]

Looking Toward the Future

For over 35 years, SunPower panels have pushed the boundaries of solar innovation. The SunPower name is renowned for its record-setting technology, industry-leading design and engineering, and the first-rate customer experience SunPower partners deliver every day.

As the manufacturer of SunPower panels, Maxeon Solar Technologies is passionate about securing these advantages. To date, more than 90 patents have already been granted to secure the inherent differentiation in SunPower Performance technology. These safeguards not only protect the panel designs and the unique processes and equipment used to manufacture them—they provide confidence to customers as well.

While many manufacturers are still in the early stages of developing varied panel technologies that rely on slicing and interconnecting portions of larger cells, the fifth generation of SunPower Performance panels is now being deployed to customers worldwide. This latest generation of shingled cell technology builds upon years of design and engineering innovation, while rapidly scaling manufacturing to meet demand from solar power plant EPCs and developers around the globe (figure 16).

To scale manufacturing rapidly, Maxeon Solar Technologies has partnered with Tianjin Zhonghuan Semiconductor (TZS). TZS is a leading mono wafer provider with more than 85 GW of planned and operating mono silicon ingot and wafer capacity. Huansheng Solar (HSPV) was formed by TZS and Maxeon Solar Technologies to combine their respective strengths in wafer technology and proximity to China's strong supply chain and logistics capacity, with Silicon Valley innovation. This joint venture solidified SunPower Performance panels' place as the leading shingled panel in terms of global deployments. In addition, it has proven both the manufacturability, as well as the strong market demand for the technology.

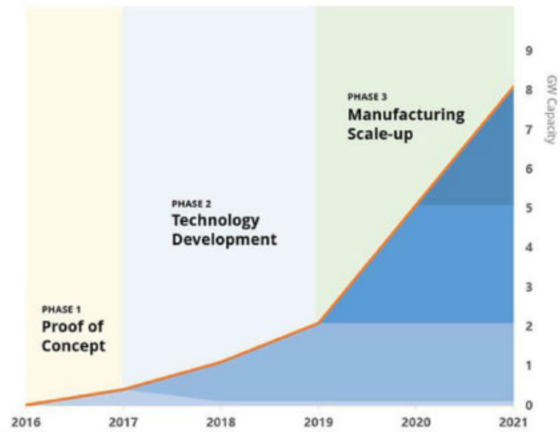

Figure 16: Taking the time to build a solid foundation centered around performance and reliability was a key factor in the scale-up of SunPower Performance panel technology.

In 2020, Maxeon Solar Technologies and TZS announced an additional 6 GW of capacity at HSPV to fuel future growth in the large-scale solar power plant market. The first 3 GW expansion phase is already delivering SunPower Performance 5 panels. An additional 3 GW will be added in 2021. Both facilities are highly automated, utilising "Factory 4.0" intelligence to digitise and optimise the entire manufacturing value chain—from raw material loading and product assembly, through testing and packaging.

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

1 Most Efficient: Based on datasheet review of websites of top 20 manufacturers per IHS, as of June 2020. Unmatched Reliability: Jordan, et. al. Robust PV Degradation Methodology and Application. PVSC 2018
2 Based on shipments as of Q2-2020
3 SunPower Performance Series – Thermal Performance, Z. Campeau 2016
4 Dupont Global PV Reliability Field Analysis (reports issued 2016, 2018 and 2019)
5 SunPower. A Comparative Study: SunPower DC Solar Module Warranty Claim Rates vs. Conventional Panels. 2019.
6 SunPower internal bifacial field test results in Davis, CA.
7 Shifeng D, et. al. Research on hot spot risk for high-efficiency solar module. Energy Procedia, ISSN: 1876-6102, Vol: 130, Page: 77-86. 2017.
8 Kato. (2012). PV module failures observed in the field: solder bond and bypass diode failures. In Characterizing and Classifying Failures of PV Modules.
9 SunPower internal study, 2020.
10 Source: Forbes, The World's Largest Oil & Gas Companies 2020. Forbes Global 2000.
11 Based review of manufacturer websites of IHS top 20 manufacturers as of Q2-20 for p-type panels.
12 Representative of standard efficiency solar manufacturers. Competitor warranty information provided from latest warranty documentation from various conventional panel manufacturer websites as of October 2020.
13 Performance panels expected useful life of 35 years. Source: "SunPower P-Series Technology Technical Review," Leidos Independent Engineer Report. 2016.