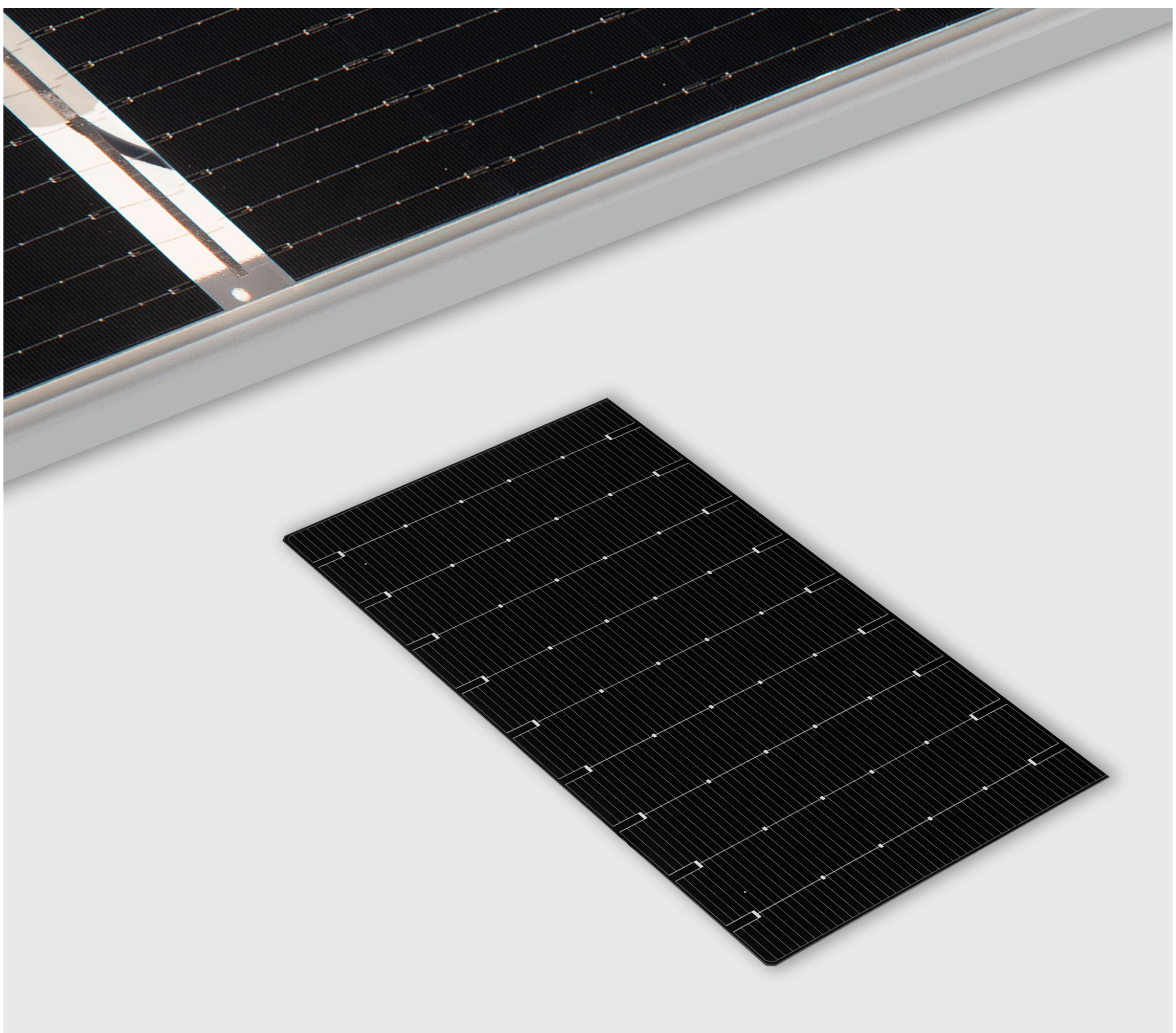
EAGLE TR G4

WHITE PAPER



JinKO Solar

1.1 EAGLE TR G4 Background

As solar competes directly with other forms of energy generation, the levelized cost of electricity increasingly comes into focus. JinkoSolar has directly addressed this trend through its recent EAGLE G2 and G3 modules, which are high-power modules with high power density and lower related BOS costs. JinkoSolar has continued to promote higher power density with the EAGLE TR (Tiling Ribbon) G4. The EAGLE TR G4 uses multi-busbar and tiling ribbon technology, in combination with high-efficiency half cut Diamond cells. The maximum power output of G4 modules reaches 475W; the maximum efficiency reaches 21.16%.

The EAGLE TR G4 includes both monofacial (G4) and bifacial (G4b) versions. The EAGLE TR G4b uses transparent DuPont™ Tedlar®-based backsheets, which ensure a 5% -30% backside energy gain and offer several key benefits due to its comparatively light weight (see Transparent Backsheet VS Dual Glass Whitepaper).

1.2 EAGLE TR G4 Module Introduction

The G4 series includes the 66TR G4 for residential customers and 78TR G4 and G4b for C&I and utility customers. Table 1 lists key characteristics of the three module types, and Figure 1 summarizes the power roadmap through 2022.

Module Type	EAGLE TR G4 66pc Monofacial All Black Module	EAGLE TR G4 78pc Monofacial Module	EAGLE TR G4 78pc Bifacial Module
Dimensions	1855 x 1029mm (73.03×40.51in)	2182 x 1029mm (85.91x 40.51in)	2205 x 1032mm (86.81x40.63in)
2021 Mainstream Mass Production	385W	465W	460W
Power Efficiency	20.17%	20.17%	20.21%

Table 1. EAGLE TR G4 Series Characteristics

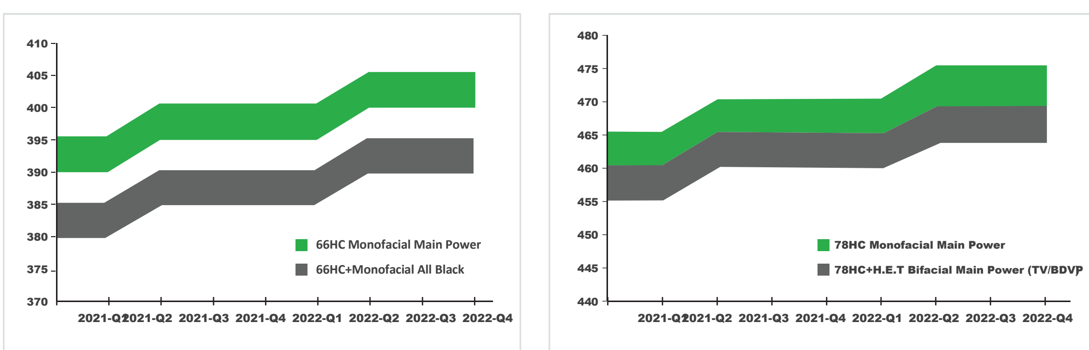


Figure 1. EAGLE TR G4 Power Roadmap

1.3 EAGLE TR G4 Module Core Technology

1.3.1 Industry-Leading Multi-Busbar Technology

The EAGLE TR G4 uses innovative multi-busbar technology, which reduces internal loss and enhances module power. Multi-busbar technology shortens the distance between the finger electrodes and each busbar, bringing down resistance losses in the cells and increasing output power/efficiency. Additionally, the EAGLE TR G4 busbars are now round, which allow them to redirect light into the cell and improve IAM significantly. JinkoSolar has experimented with the number of busbars, and the results are shown in Figure 2. The module power goes up as more busbars are added, and peaks around eight to ten busbars, representing the sweet spot between reduced resistance losses and excessive shading by the busbars themselves. With an eye towards power and precision, JinkoSolar uses nine busbars for the EAGLE TR G4.

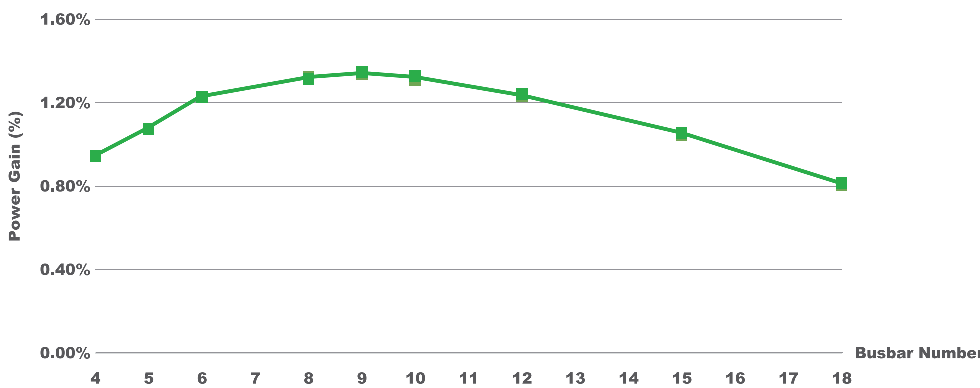


Figure 2. Multi-Busbar Power Gain

1.3.2 Better Efficiency with Tiling Ribbon Technology

To increase power density, the EAGLE TR G4 uses tiling ribbon technology (details in Figure 3 below) which eliminates the cell gap, allowing for more cells to be packed into a module. Tiling ribbon technology enables G4 modules to achieve efficiencies higher than 20.7%.

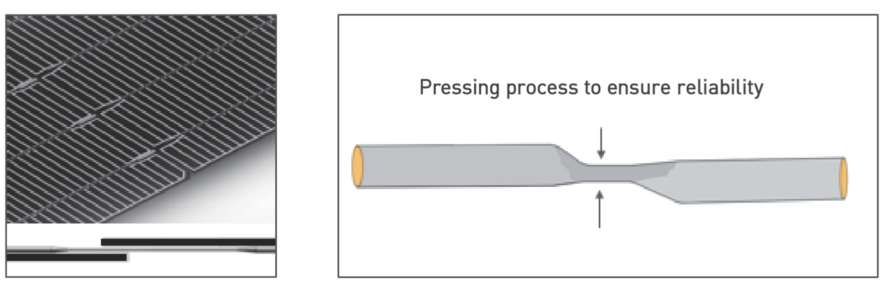


Figure 3. Tiling Ribbon Technology

1.3.3 Improved Reliability with Tiling Ribbon

The tiling ribbon technology improves reliability of the module in two key ways. First, the tiling ribbon used is a flexible round wire ribbon that is flattened at the area of overlap (see Figure 3). This decreases mechanical stress on the cell edges. Second, the tiling ribbon is used in conjunction with special EVA or POE that is used to fill the overlapping areas during lamination. This not only creates a buffer around the cells and ribbon, providing additional cushion, but also adds elasticity to the area which helps to absorb stress and minimize microcracks.

Results from double IEC testing on EAGLE TR G4b modules are shown below in Figure 4. Degradation after testing for EAGLE TR G4b is significantly lower than 5% across all the tests, which demonstrates better performance than any previous generation modules. This shows that EAGLE TR G4 modules are not only more efficient but also more reliable, making them a good choice for stable return on investment.

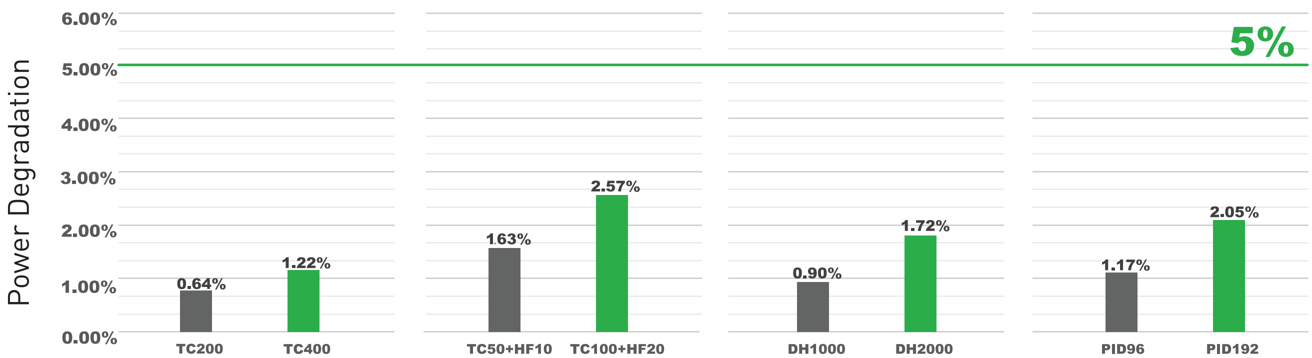


Figure 4. EAGLE TR IEC Testing Results

Of note, the EAGLE TR G4 has a larger footprint than previous generations but maintains excellent mechanical load. After dynamic mechanical load testing (1000 cycles at ± 1000Pa), the resulting front-side power degradation rate is 0.6%, and back-side power degradation rate is 1.68%, far lower than the 5% maximum stipulated by IEC standards. In static mechanical load testing (frontside 5400Pa, backside 2400Pa), the resulting front-side power degradation is only 0.3%, and the back-side power degradation is 1.82%.

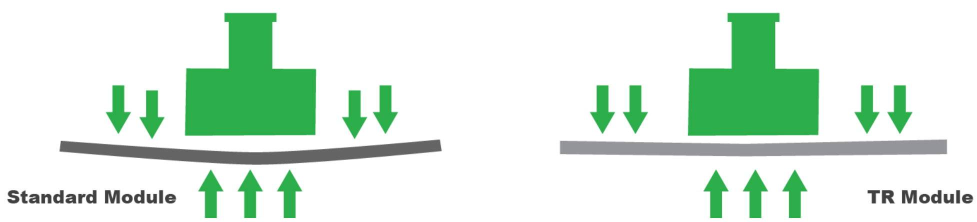


Figure 5. EAGLE TR Loading Tests

1.3.4 Half Cell Technology

The EAGLE TR G4 continues to use half cut cells. Half-cell technology decreases internal resistance which reduces internal power loss, allowing for higher power output and better reliability. The front-side power output of half-cell modules can achieve up to 15Wp more than normal full cell modules. Moreover, hot-spot risk is lower in half-cell modules. As shown in Figure 6, the average temperature difference in half-cell is 1.8°C lower.

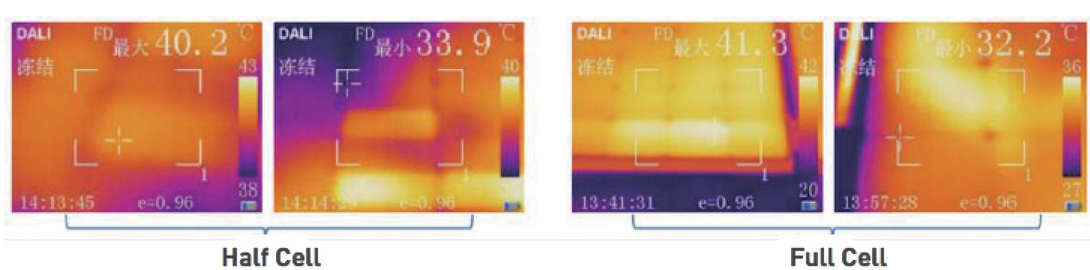
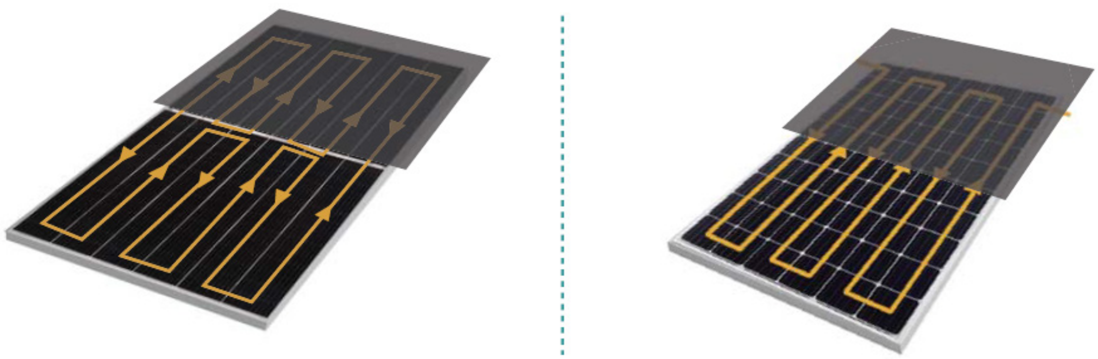


Figure 6. Working Temperature Between Half Cell & Full Cell

When installed vertically, half-cell technology also cuts down losses from shading. In the half-cell module, the upper part and lower part of the module are connected in parallel. When 50% of the module surface is shaded, a half-cell module will still generate 50% of its nominal power, while full cell modules in an equivalent situation will generate 0 power (see Figure 7). The half cell module also has a better temperature coefficient. The temperature coefficient of JinkoSolar's half-cell module is -0.35%/ºC, while that of the full-cell module is -0.37%/ºC. This means a half-cell module will have higher power than a full-cell module when operating in hot areas with temperatures up to 75ºC.



~50% Power Output   0 Power Output

Figure 7. Module output under shading environment

2. EAGLE TR G4 System Design

2.1 1500V compatibility of EAGLE TR G4 module

EAGLE TR G4 modules are manufactured with lower open circuit voltage. This allows more modules to be connected in a single string, which saves balance of system costs. In different project sites, the number of modules that can be connected in a string depends on the local irradiation and temperatures. Jinko simulated and tested the V_{OC} of a 460W EAGLE TR G4 monofacial module under different irradiances and cell temperatures. From this, Jinko calculated the number of modules that could be connected in a 1500V string, and the results are summarized in Table 2 below.

The green highlighted portion in Table 2 indicates conditions where more than 29 modules can be connected in one 1500V string. Cell temperature (T_{cell}) is calculated using the formula:

$$T_{cell} = T_{amb} + (1/U) * G_{POA} * alpha * (1 - efficiency)$$

Where heat transfer coefficient $U = U_c + U_v * v_{wind}$, U_c = system conductive heat transfer coefficient, U_v = wind convective heat transfer coefficient, vwind = wind speed in project area, G_{POA} = actual irradiance (direct light + scattered light), alpha = absorptivity, and efficiency = actual module efficiency.

Cell Temperature

Irradiance	-9°C	-6°C	-3°C	0°C	3°C	6°C	9°C	12°C	15°C	18°C	21°C	24°C	27°C
10W/m²	**30.0**	**31.0**	**31.0**	**31.0**	**32.0**	**32.0**	**32.0**	**30.0**	**33.0**	**34.0**	**34.0**	**34.0**	**35.0**
20W/m²	**30.0**	**30.0**	**30.0**	**30.0**	**31.0**	**31.0**	**31.0**	**30.0**	**32.0**	**33.0**	**33.0**	**33.0**	**34.0**
30W/m²	**29.0**	**29.0**	**30.0**	**30.0**	**30.0**	**31.0**	**31.0**	**30.0**	**32.0**	**32.0**	**32.0**	**33.0**	**33.0**
40W/m²	**29.0**	**29.0**	**29.0**	**30.0**	**30.0**	**30.0**	**31.0**	**30.0**	**31.0**	**32.0**	**32.0**	**32.0**	**33.0**
50W/m2	**29.0**	**29.0**	**29.0**	**29.0**	**30.0**	**30.0**	**30.0**	**30.0**	**31.0**	**31.0**	**32.0**	**32.0**	**32.0**
60W/m²	28.0	**29.0**	**29.0**	**29.0**	**30.0**	**30.0**	**30.0**	**30.0**	**31.0**	**31.0**	**31.0**	**32.0**	**32.0**
70W/m²	28.0	**29.0**	**29.0**	**29.0**	**29.0**	**30.0**	**30.0**	**30.0**	**31.0**	**31.0**	**31.0**	**32.0**	**32.0**
80W/m²	28.0	28.0	**29.0**	**29.0**	**29.0**	**30.0**	**30.0**	**30.0**	**30.0**	**31.0**	**31.0**	**31.0**	**32.0**
90W/m²	28.0	28.0	**29.0**	**29.0**	**29.0**	**29.0**	**30.0**	**30.0**	**30.0**	**31.0**	**31.0**	**31.0**	**32.0**
100W/m²	28.0	28.0	28.0	**29.0**	**29.0**	**29.0**	**30.0**	**30.0**	**30.0**	**30.0**	**31.0**	**31.0**	**31.0**
200W/m²	27.0	28.0	28.0	28.0	28.0	**29.0**	**29.0**	**29.0**	**29.0**	**30.0**	**30.0**	**30.0**	**31.0**
300W/m²	27.0	27.0	27.0	27.0	28.0	28.0	28.0	**29.0**	**29.0**	**29.0**	**29.0**	**30.0**	**30.0**
400W/m²	27.0	27.0	27.0	27.0	28.0	28.0	28.0	28.0	**29.0**	**29.0**	**29.0**	**29.0**	**30.0**
500W/m²	27.0	27.0	27.0	27.0	27.0	28.0	28.0	28.0	28.0	**29.0**	**29.0**	**29.0**	**29.0**
600W/m²	26.0	27.0	27.0	27.0	27.0	28.0	28.0	28.0	28.0	28.0	**29.0**	**29.0**	**29.0**
700W/m²	26.0	27.0	27.0	27.0	27.0	27.0	28.0	28.0	28.0	28.0	**29.0**	**29.0**	**29.0**
800W/m²	26.0	26.0	27.0	27.0	27.0	27.0	27.0	28.0	28.0	28.0	28.0	**29.0**	**29.0**
900W/m²	26.0	26.0	27.0	27.0	27.0	27.0	27.0	28.0	28.0	28.0	28.0	**29.0**	**29.0**
1000W/m²	26.0	26.0	26.0	27.0	27.0	27.0	27.0	27.0	28.0	28.0	28.0	28.0	**29.0**

Table 2. Number of EAGLE TR G4 modules that can be connected in one 15000V string under different temperatures and irradiances

As an example (using conditions of a project in Australia), assume that when the inverter reaches starting voltage, the irradiance is 200 W/m^2 and environment temperature is 0°C. With U_c = 29W/m^2K, U_v = 1.6W/m^2K, alpha = 0.9, and efficiency = 20.71%, the cell temperature would be 6.28°C, and from Table 2, it can be concluded that 29pcs/string would be safe to use. Customers can use the results in Table 2 to take advantage of the low V_{OC} EAGLE TR G4 modules in 1500V system designs. JinkoSolar plans to conduct technology reviews with inverter suppliers to ensure safety standards.

2.2 Compatibility with Trackers

The EAGLE TR G4 module is compatible with mainstream trackers and fixed racks without modification, which prevents unnecessary cost increases. JinkoSolar collaborated with mainstream tracker companies before launching the EAGLE TR G4 module. Although the EAGLE TR G4 is longer than previous generation modules, the higher efficiency will decrease the land area required while maintaining the same power generation, decreasing tracker costs.

Table 3 below shows the example parameters of two module strings using a 1P tracker. Compared with a previous generation 5BB module, the EAGLE TR G4 module delivers the same total power output per string, but using 3% less area. This means less steel and trackers for the customer, lowering BOS costs.

	EAGLE G2	EAGLE TR G4
Power Class (W)	405	465
Module Efficiency (%)	19.78	20.43
Pcs/string	30	26
Total String Power Output (kW)	12.15	12.15
Area Required (m^2)	61.4	59.5

Table 3. Comparison of 12.15 kW Module Strings for 5BB Module vs EAGLE TR G4

3. Energy Generation Performance

3.1 IAM advantage

The EAGLE TR G4 module uses 9 busbars and a round wire ribbon design as seen in the photo below. Round wire ribbons redirect light from the sides of the ribbon to the cell, which increases energy generation. The original 5 busbar design does not use these round ribbons and therefore reflects more light.

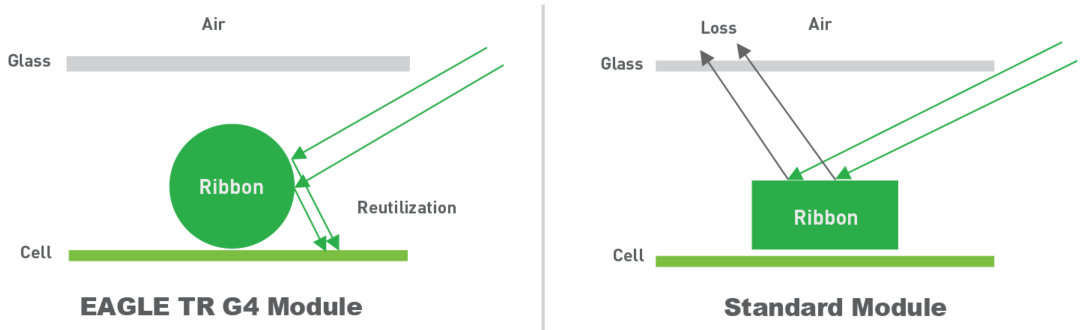


Figure 8. Round wire ribbon energy gain

Below is a PAN file report for IAM values from SGS. The data shows that the EAGLE TR G4 module has excellent energy generation performance, even at high incidence angles.

Table: IEC61853-2: 2016					**—**
Test Date (MM/DD/YYYY)...:			02/14/2020		—
Sample # ...:			04		—
Angle (θ)	Isc (θ) [A]	Isc (θ) diffuse [A]	Isc (θ) corr [A]	Isc (θ) corr/ cos (θ) [A]	Relative Transmission $\tau(\theta)$
85	0.612	0.201	0.223	2.125	0.857
80	0.788	0.332	0.469	2.845	0.932
75	1.378	0.533	0.863	3.408	0.963
70	1.961	0.749	1.256	3.718	0.982
65	2.510	0.871	1.652	3.954	0.991
60	3.214	1.102	2.073	4.065	1.000
50	3.876	1.262	2.789	4.265	1.000
40	4.722	1.335	3.391	4.298	1.000
30	5.294	1.423	3.878	4.451	1.000
20	5.676	1.511	4.193	4.462	1.000
10	5.887	1.542	4.415	4.398	1.000
0	6.053	1.581	4.503	4.622	1.000

Figure 12. 3rd party IAM testing

3.2 Low Irradiance Advantage

The EAGLE TR G4 module uses an optimized circular ribbon, which has a significantly reduced cross-sectional area compared to the previous flat ribbon. The reduction of cross-sectional area decreases ribbon shielding on the cell, which increases light exposure area thereby increasing module power. This provides an advantage in power generation under low irradiance. While a smaller ribbon cross-sectional area does result in higher module series resistance, the associated decrease in power output is outweighed by the increase in low irradiance generation.

In CPVT measured PR data (below in Figure 10), the EAGLE TR G4 module can be seen to have clear advantages in power generation under lower irradiances, compared to a standard 5BB module.

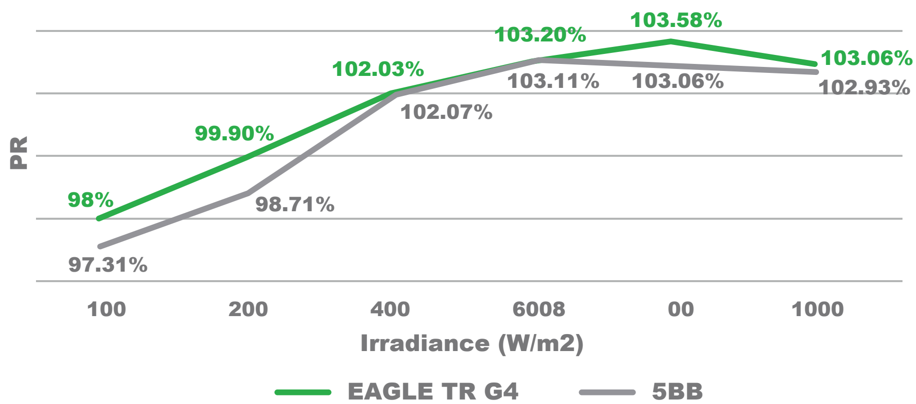


Figure 10. CPVT outdoor testing comparing PR for EAGLE TR G4 and 5BB at multiple irradiances

To demonstrate this advantage, JinkoSolar also conducted outdoor tests of a 5BB mono PERC module and a 9BB EAGLE TR G4 module at the JinkoSolar R&D Center located in Haining, China The results are displayed in Figure 11.

The EAGLE TR G4 module achieved an average power generation gain of 1.57% compared to a 5BB module. The results also show that the EAGLE TR G4 module achieved power generation gains of 1.91% and 1.72% compared to a 5BB under low irradiance (data from 9/21 and 9/22).

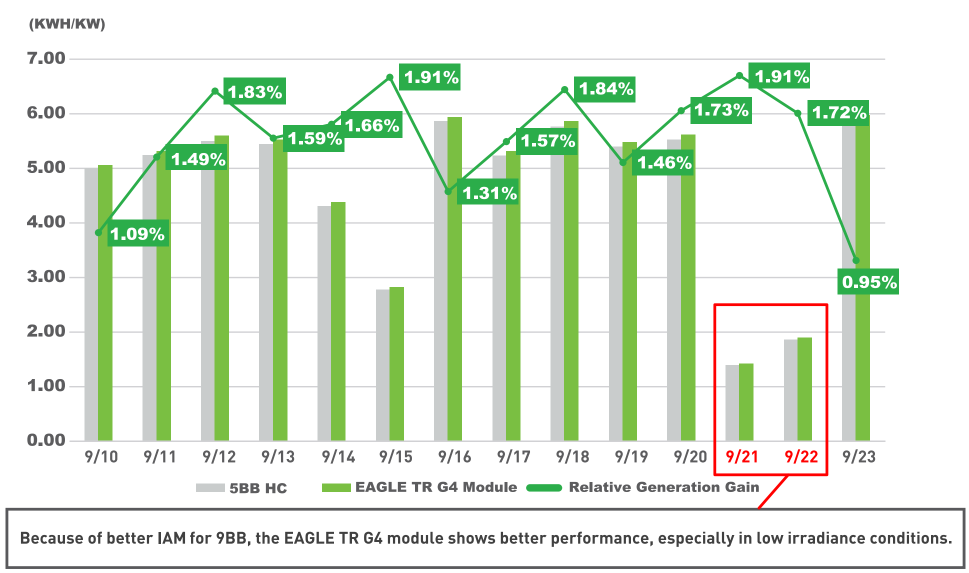


Figure 11. EAGLE TR G4 module energy gain

Statement

This report was written by Jinko Solar Co., Ltd. (hereinafter referred to as "we, us, our, and ours" This report is based on legally obtained information, but we do not guarantee the accuracy and completeness of such information. Part of the analysis included in this report is based on various assumptions, which may lead to significant differences in the analysis results. The contents and opinions in the report are for reference only.