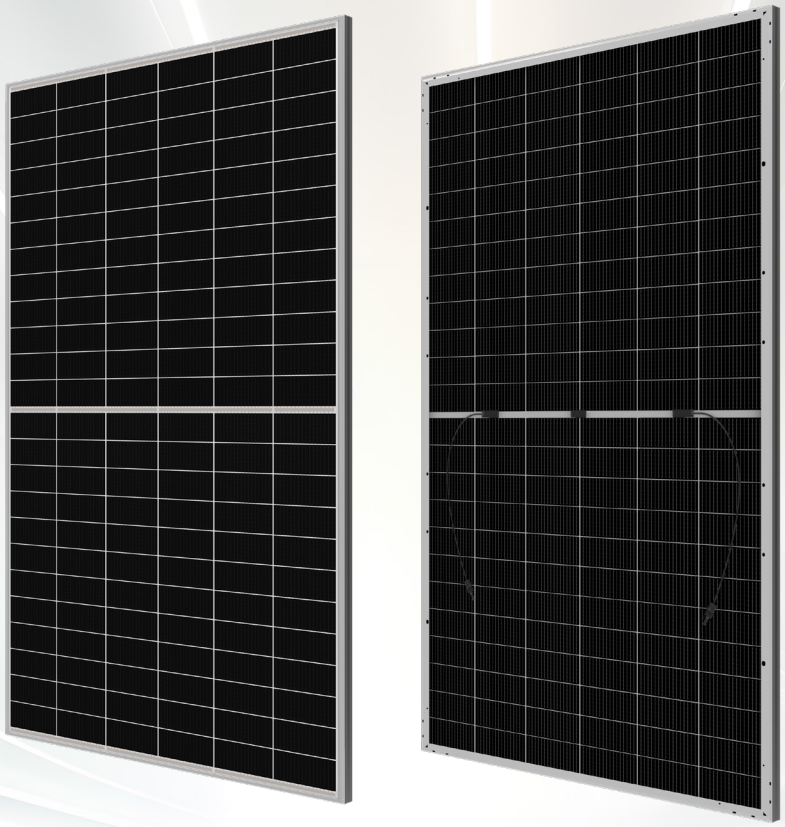
CanadianSolar



CSI 182 Plus
High Efficiency TOPCon Modules

Product White Paper

CSI Solar Co., Ltd.

2024 March

1. Introduction

Canadian Solar was founded in 2001 in Canada and is one of the world' s largest solar technology and renewable energy companies. It is a leading manufacturer of solar photovoltaic modules, provider of solar energy and battery storage solutions, and developer of utility-scale solar power and battery storage projects with a geographically diversified pipeline in various stages of development. Over the past 22 years, Canadian Solar has successfully delivered over 110 GW of premium-quality, solar photovoltaic modules to customers more than 160 countries around the world.

CSI solar, the majority-owned subsidiary of Canadian Solar, has module production capacity of 57GW by the end of 2023, and will reach 61GW by the end of 2024. CSI Solar also R&D and produces high efficiency PV inverters and energy storage for residential & commercial solar systems and utility solar plants.

Likewise, since entering the project development business in 2010, Canadian Solar has developed, built, and connected around 9.3 GWp of solar power projects and over 3 GWh of battery storage projects across the world. Currently, the Company has around 850 MWp of solar power projects in operation, 7.8 GWp of projects under construction or in backlog (late-stage), and an additional 18.7 GWp of projects in the advanced and early-stage pipeline. In addition, the Company has a total battery storage project development pipeline of approximately 55 GWh, including approximately 5 GWh under construction or in backlog, and an additional 50 GWh at advanced and early-stage development. Canadian Solar is one of the most bankable companies in the solar and renewable energy industry, having been publicly listed on the NASDAQ since 2006.

2. CSI 182 Plus TOPCon Module – Higher Power, More Reliable

CSI Solar is committed to enhancing the performance and dependability of its solar modules, while consistently delivering top-notch products to its customers. Through proactive exploration of cutting-edge module technologies, the company continually introduces products that boast increased energy output, including large-dimension wafers, N-type HJT cells, and TOPCon (Tunnel Oxide Passivated Contacts) modules. Since 2019, CSI Solar has been dedicated to the development of N-type TOPCon technology.

After years of dedicated research and development, CSI Solar has introduced its N-type TOPCon high-efficiency module, distinguished by its unwavering reliability and innovative design. This module is available in both 182mm and 210mm cells, offering flexibility for diverse applications. Moreover, it is offered in both single-glass and double-glass modules and various module formats and power outputs.

Furthermore, CSI Solar challenges conventional norms by optimizing module design to align with container dimensions. This evolution includes upgrading from the 182 TOPCon to the 182 Plus TOPCon, leveraging in-house capabilities spanning from ingot production to cell and module manufacturing, thereby enhancing the product line comprehensively. The 182 Plus module offers innovative solutions for both distribution and utility-scale applications. By maximizing container space utilization and delivering higher power output, this advancement not only reduces Balance of System (BOS) costs and Levelized Cost of Energy (LCOE) but also adds significant value for customers.

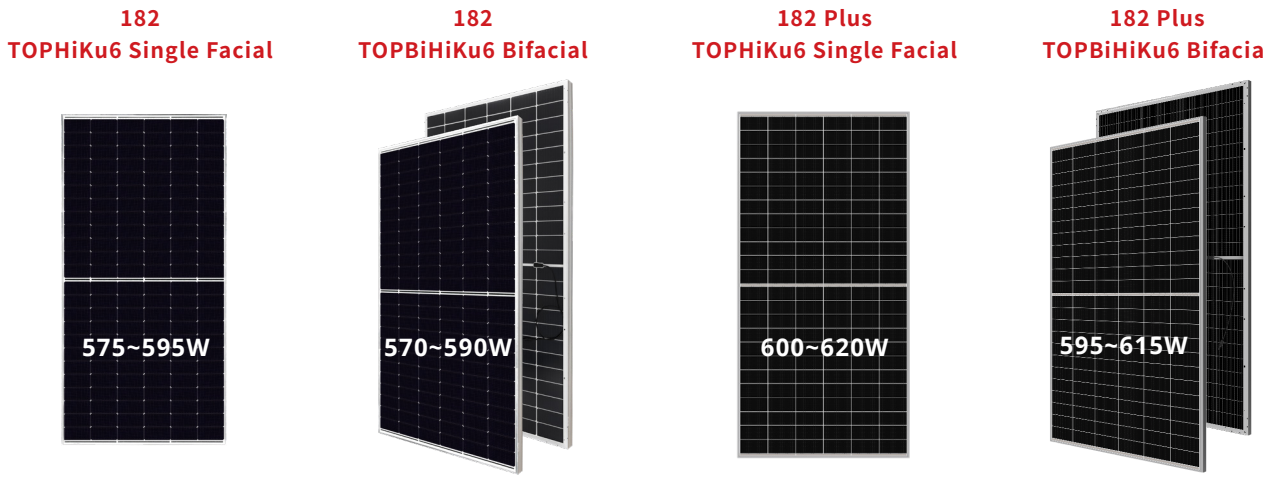


Figure 1. CSI TOPCon Module Family

Cell	182 TOPCon		182 Plus TOPCon	
Module Power (W)	575~595	570~590	600~620	595~615
Model Type	CS6W-T	CS6W-TB-AG	CS6.1-72TD	CS6.1-72TB
Module Efficiency	23.0%	22.8%	23.0%	22.8%
Module Size (mm)	2278×1134×30	2278×1134×30	2382×1134×30	2382×1134×30

Table 1. Key Parameters of 182 & 182 Plus TOPCon Modules

CSI 182 Plus TOPCon Module: Elevating Quality Through In-House Material Manufacturing Capabilities

CSI Solar's in-house 182 Plus TOPCon ingot with higher quality lays the foundation for high-efficiency, low-degradation modules. Ingot with larger diameter helps improve production capacity and efficiency, and its various quality properties meet the highest standards in the industry, such as oxygen content being controlled at 10~11ppma, minority carrier lifetime at ingot top being controlled at 6000us.

CSI Solar's in-house 182 Plus TOPCon cells are produced by adopting PECVD measure, which is relatively difficult but has obvious advantages in mass production. Through in-depth researching, we have managed to solve some difficult problems during the manufacturing process. Currently, 182 Plus TOPCon cells reached the efficiency up to 26.3% in mass production.

CSI Solar's 182 Plus TOPCon module is meticulously crafted with a thorough analysis of diverse application scenarios and compatibility with various racking systems. Following rigorous testing at the CSI Solar Test Center, the module exhibited a degradation rate of less than 2%. CSI Solar's 182 Plus TOPCon modules feature lower operating temperatures, excellent power generation performance, high reliability, and long warranty.

CSI 182 Plus TOPCon Module, Enhanced Power Output in High-Temperature

The operating temperature of modules significantly influences their power output. The CSI 182 Plus TOPCon modules utilize N-type silicon wafers with extended minority carrier lifetimes, coupled with the implementation of advanced tunnel oxide passivating contacts technology. This approach involves enhancing the cell's open-circuit voltage (Voc) through the deposition of an ultra-thin oxide layer and the doping of a polysilicon layer on the cell's rear, thereby facilitating effective interface passivation. The resulting higher open-circuit voltage contributes to a more favorable module temperature coefficient.

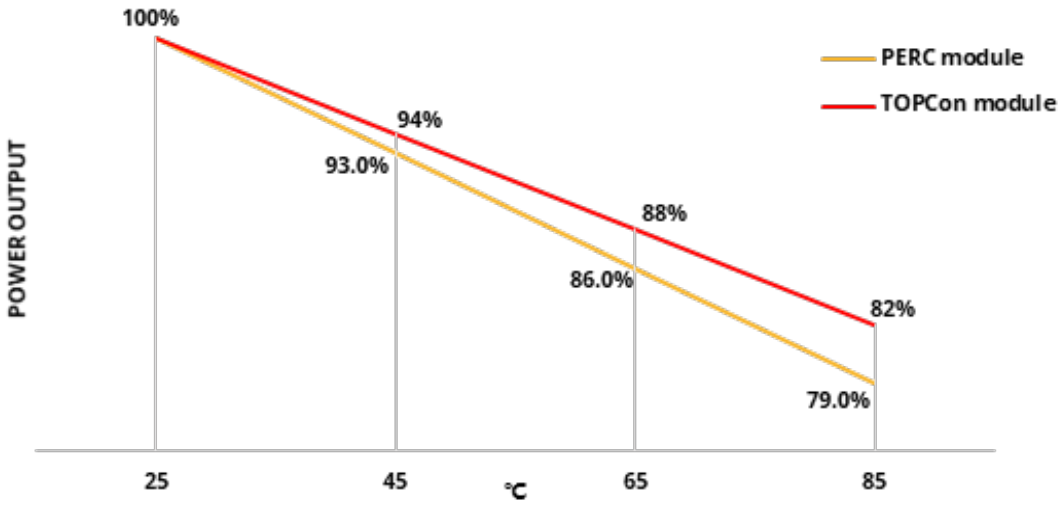


Figure 2. Influence of module temperature on its power output

As a result, 182 Plus TOPCon modules performs better than PERC modules when operating in high temperature environments (Figure 2).

CSI 182 Plus TOPCon Module, Better Performance and Reliability

CSI Solar has embraced an industry-leading technology known as Laser Induced Firing (LIF) in the manufacturing of 182 Plus TOPCon cells. This cutting-edge approach involves subjecting the cell to a high-intensity laser at a specific process temperature while applying a bias voltage. This technique effectively reduces the contact resistance between the metal and the semiconductor, thereby increasing the Fill Factor (FF). Additionally, it enables the achievement of passivation recovery effects, resulting in a significant enhancement of the cell's Voc (open-circuit voltage). Mass production verification has demonstrated that the integration of LIF technology with designated paste can elevate cell efficiency by 0.3%. This improvement includes an increase in Voc by 3.8mV and FF by 0.5% (Figure 3).

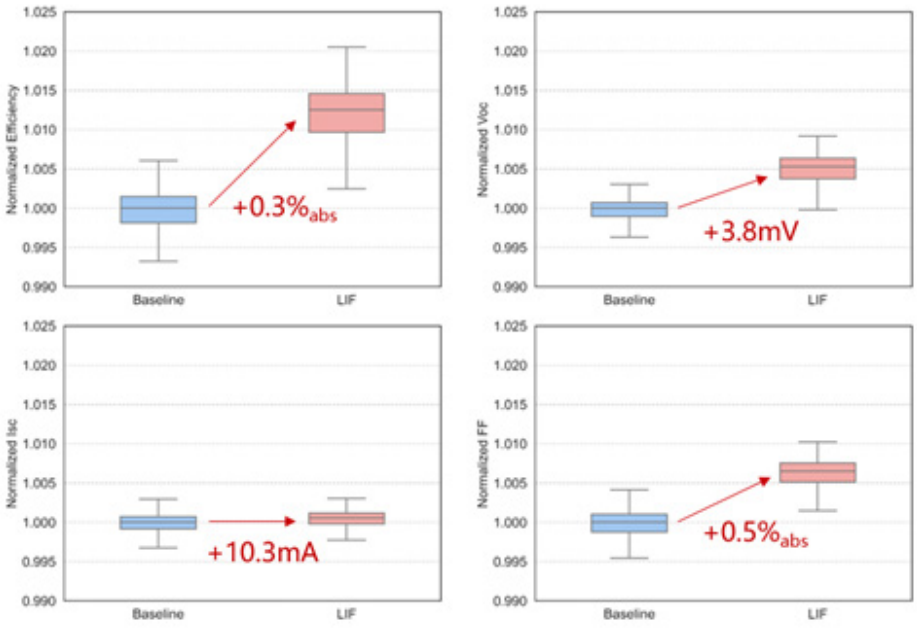


Figure 3. LIF improves TOPCon cell performance

In the cell design, narrower and more numerous finger grid lines are implemented. This minimizes transmission distances, resulting in reduced shading areas and effectively lowering series resistance and silver paste consumption. Through simulation and experimental validation, it has been determined that 16 busbars (16BB) represent the optimal configuration for maximizing module power output for both the 182 and 182 Plus TOPCon modules.

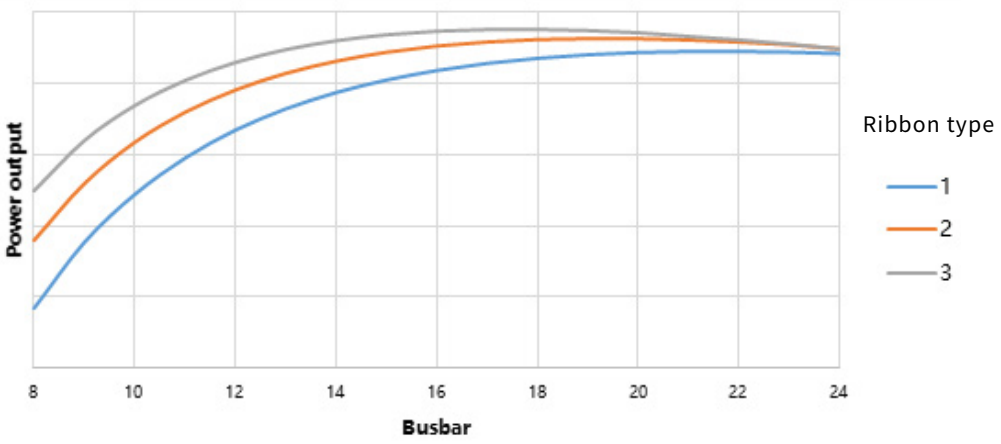


Figure 4. Relationship between number of busbar and power output

182 TOPCon cell is developed with N-type wafer of long minority carrier lifetime which could reach 2ms. Meanwhile, a symmetrical design on cell' s front and back sides allows for TOPCon module' s less shading area compared to PERC. With multiple bifaciality increase technologies on both cell and module levels combined, CSI 182 Plus TOPCon modules can see bifaciality of up to 85%.

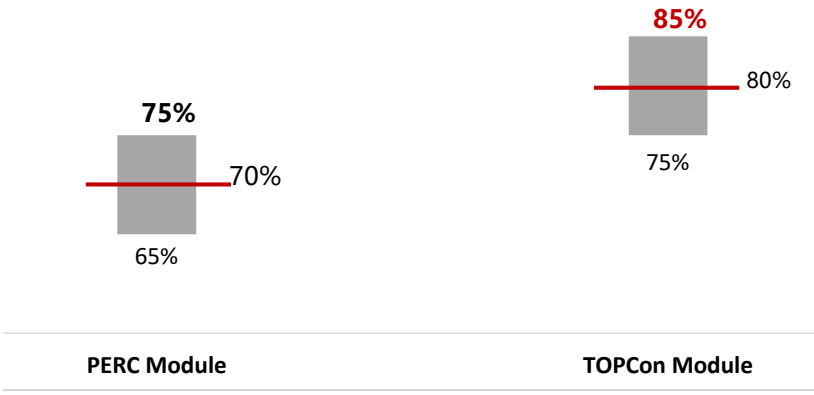


Figure 5. Bifaciality of PERC and TOPCon modules

Moreover, the CSI Solar 182 Plus TOPCon module has been crafted with a focus on reliable product design and manufacturing technologies. This includes advanced processes such as non-destructive cell dicing, precise soldering (Figure 6), and high-density stringing technology. These features ensure the performance and reliability of the modules.

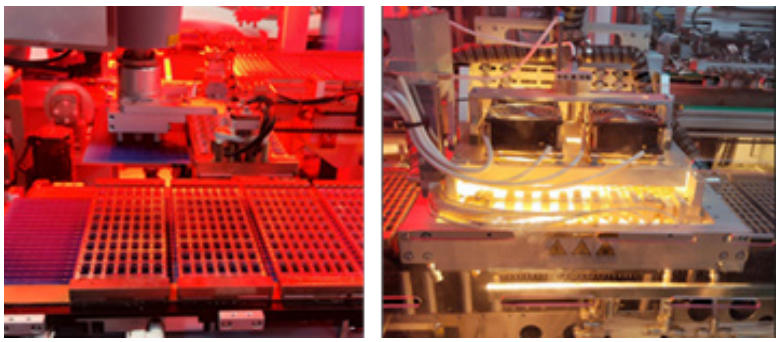


Figure 6. Non-destructive cell dicing and precise soldering for TOPCon modules

CSI 182 Plus TOPCon Module, Industry Leading Extended Reliability Testing

CSI has established in-house reliability testing protocol with testing doses of 2 times and even 3 times of IEC standard to ensure great product reliability (Table 2).

Test	IEC 61730/61215	CSI Extended Reliability Testing
DH	1000h	2000h
TC	200 cycles	400~600 cycles
HF	10 cycles	20~30 cycles
PID	96h	192h

Table 2. Comparison of IEC Standard and CSI standard

Our test results show that 182 Plus TOPCon modules performed better compared to PERC modules.

Taking Damp Heat (DH) for example, 182 Plus TOPCon bifacial modules showed less than 1% power degradation after DH2000 testing, which was much lower than 5% required by IEC standard after DH1000.

CSI Solar optimized cells' UV resistance through proper light injection together with annealing and anti-reflection design. CSI Solar also developed a cell-level UV assessment method for daily monitoring. After UV irradiation of 60kWh/㎡, TOPCon cells showed about 0.2% less degradation compared to PERC cells (Figure 7).

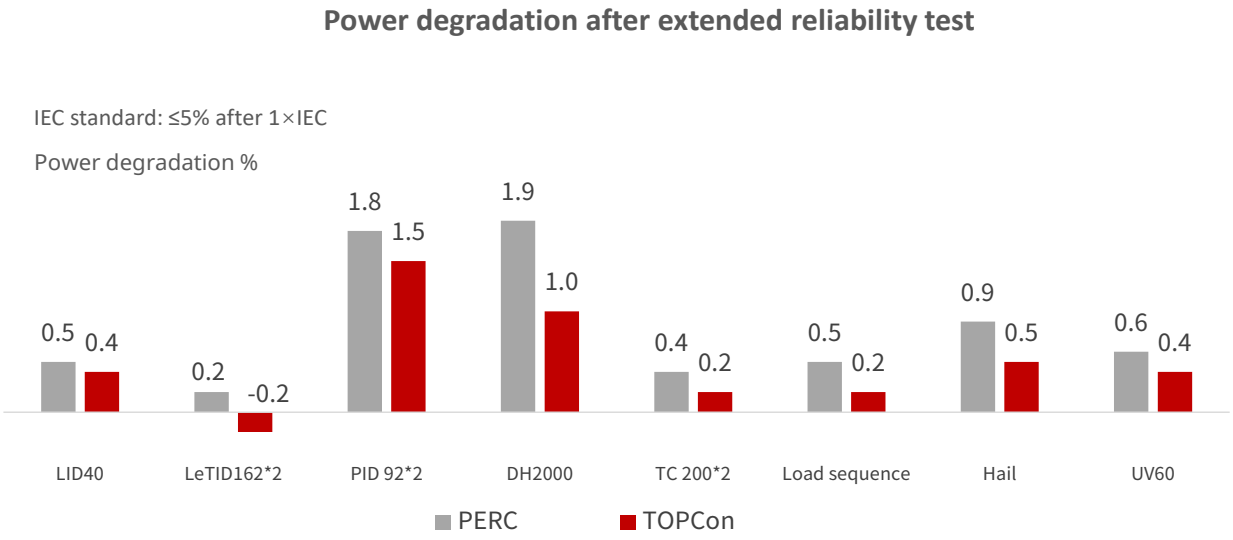


Figure 7. Reliability test results of PERC and TOPCon modules

CSI 182 Plus TOPCon Module, Longer Warranty, Lower Power Degradation

Symmetrical design on the front and back sides of 182 Plus TOPCon cells reduces internal stress and enhances module resistance under temperature changes. Furthermore, higher minority carrier lifetime and no boron-oxygen related degradation bring TOPCon modules lower degradation rate. In addition, high quality encapsulation and advanced module manufacturing technologies further enhance TOPCon modules' performance.

CSI Solar offers 30-year power warranty for TOPCon modules and guarantees power degradation less than 1% in the first year and less than 0.4% per year thereafter. Longer module warranty and lower power degradation significantly increase power output in modules' lifetime (Figure 8).

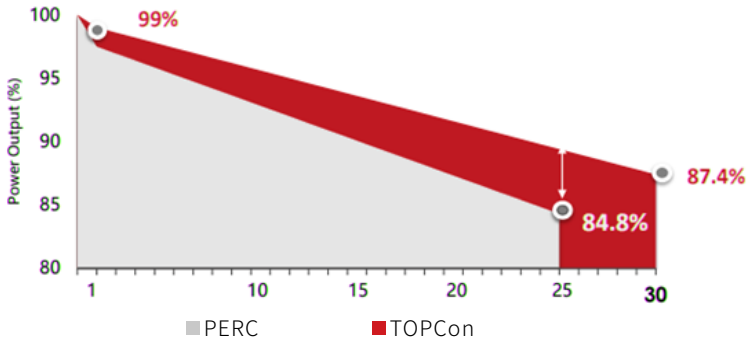


Figure 8. Lifetime power output of TOPCon and PERC modules

3. CSI 182 Plus TOPCon Module, More Energy Yield, Lower LCOE

In order to understand TOPCon modules' performance compared to PERC modules, CSI Solar simulated system performance among 182 PERC, 182 TOPCon and 182 Plus TOPCon modules based on a 28.7MW solar farm located in Los Angeles, U.S.

Module Type	182 PERC bifacial-555W	182 TOPCon bifacial-585W	182 Plus TOPCon bifacial-610W
Power (W)	550	585	610
Module Area (m²)	2.6	2.6	2.7
Module Efficiency	21.50%	22.60%	22.60%
Module Open-Circuit Voltage(V)	49.8	52.4	52.2
Annual Degradation Rate	0.45%	0.40%	0.40%
Site	Los Angeles, USA		
DC System Size (MWdc)	28.7		
DC/AC Ratio	1.3		
Project site area (m2)	Same area		
Installation Method	Single-axis tracked (1 row portrait installation)		
Service Life	30 years		
Ground Coverage Ratio	0.33	0.31	0.31
Pitch (m)	6.9	7.28	7.59
Module Number/String	28	27	27
String Number per table	3		
Module Number per table	84	81	81
Module Power per rack (W)	46620	47385	49410
Total Length per rack table (m)	98.1	94.6	94.6
Total Module Area per table rack (m²)	217	209.2	218.8

Table 3. Parameters used in system performance simulation

Simulation results showed that energy yield of 182 Plus TOPCon modules would be about 2.3% higher than that of PERC modules during 30-year lifetime (Figure 9).

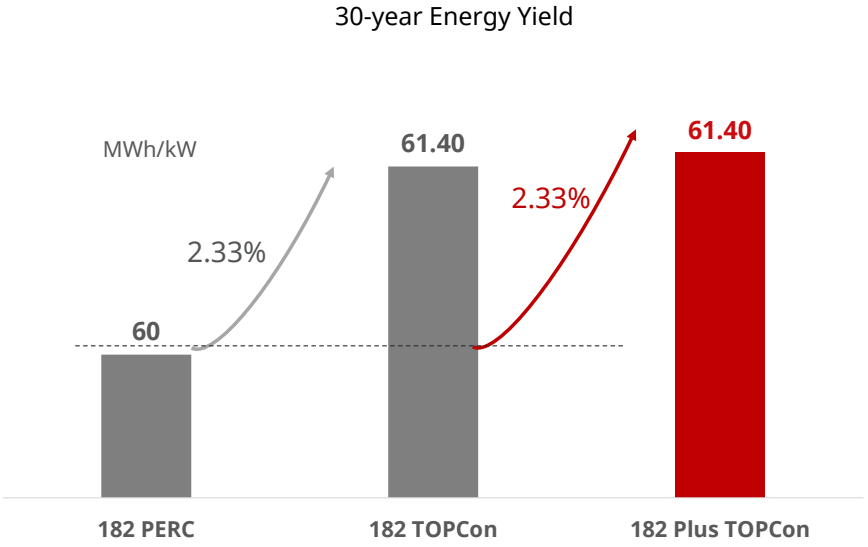


Figure 9. Comparison of energy yield between PERC and TOPCon bifacial modules

CSI 182 Plus TOPCon Module, Lower BOS Cost

Due to higher power of 182 Plus TOPCon bifacial module, less modules will be required for similar DC capacity. Subsequently, other costs for examples, installation and racks, will also be reduced.

After calculation, the overall BOS cost of 182 Plus TOPCon bifacial module is expected to decrease by about 1.9% (Table 4).

Module Type	182 PERC bifacial-555W	182 TOPCon bifacial-585W	182 Plus TOPCon bifacial-610W
Module Installation Cost	100%	95.2%	93.2%
Rack Material Cost	100%	95.5%	93.0%
Rack Installation Cost	100%	96.0%	94.4%
Material and Installation Cost of Cable and Combiner Box	100%	108%	104%
Development Cost	100%	99.4%	98.6%
Total BOS Cost	100%	99.2%	98.1%

Table 4. Comparison of BOS cost between PERC and TOPCon modules

CSI 182 Plus TOPCon Module, Lower LCOE

Based on above simulation, CSI Solar found that the LCOE of system using PERC bifacial modules would be about 28.2$/MWh, while the LCOE of system using 182 Plus TOPCon bifacial modules would be about 27.4$/MWh, about 2.8% less compared to PERC case (Figure 10).

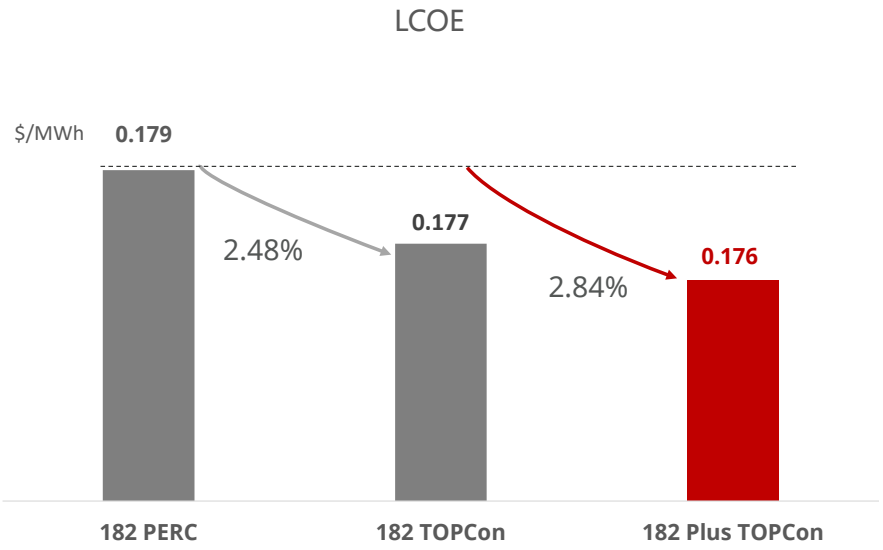


Figure10. LCOE comparison between systems with TOPCon and PERC bifacial modules

CSI 182 Plus TOPCon Module, 99.8% of Container Space Utilization Rate, Decreasing Shipping Cost

CSI 182 Plus TOPCon module is based on a rectangular wafer design, tapping the potential of the module in the length direction. It improves both module power and container utilization rate at the same time.

For instance, considering a 40-foot high-cube container, it can accommodate 720 modules with a total power output of approximately 389 kW for 182 PERC 72-cell modules. In contrast, for 182 TOPCon modules of the same format, the total power increases to about 410 kW. However, with 182 Plus TOPCon modules, the container can hold around 439 kW of modules, marking a notable increase of approximately 13.05% compared to PERC modules.

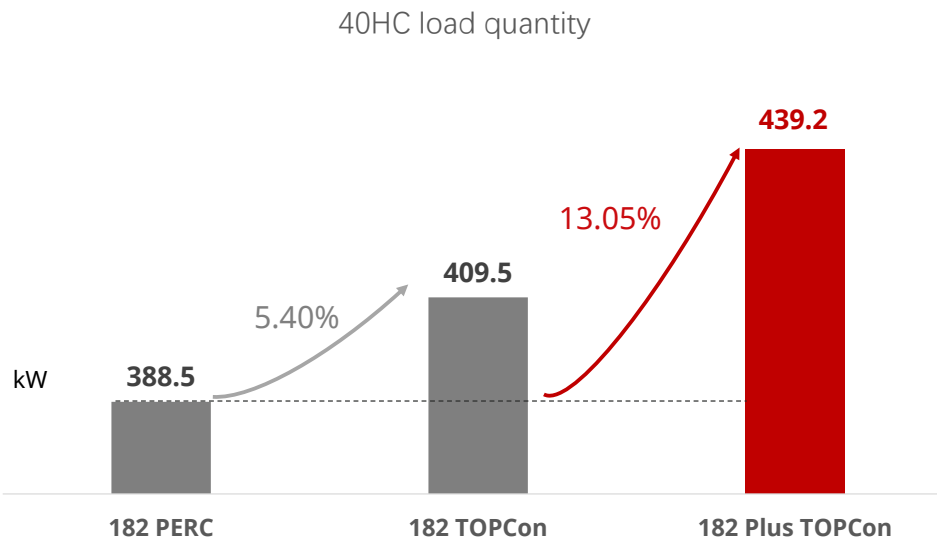


Figure11. Loading capacity comparison among 182 PERC, 182 TOPCon and 182 Plus TOPCon

CSI 182 Plus TOPCon Module, Great System Compatibility

182 Plus TOPCon modules are compatible with mainstream mounting systems, whether fixed mounting systems or trackers, such as Nextracker, Soltec, Array, Arctech Solar PVH and others (Figure 12).

Figure 12. Mainstream rack manufacturers

CSI Solar cooperates with major inverter manufacturers to provide customers with complete string inverter solutions. Currently, 182 Plus TOPCon modules are compatible with well-known string inverter brands including: Sungrow, Ginlang, Huawei, etc (Figure 13). Compared with 182 TOPCon, 182 Plus modules working with 30A/MPPT string inverters can fully utilize the MPPT current, while inverter' s over-matching loss is almost the same. With higher module power, 182 Plus TOPCon module can further improve the DC/AC ratio to lower LCOE, thus more profits can be achieved.

Figure13. Mainstream inverter suppliers

4. CSI 182 Plus TOPCon Module, A Better Choice than 182 TOPCon

By 2024, the photovoltaic (PV) industry is poised for a comprehensive transition from P-type to N-type technology. Presently, several emerging technologies, notably TOPCon, HJT, and BC, have progressed to mass production stages. CSI Solar has development plans for all three. Notably, CSI Solar has achieved full production capacity of 30GW for TOPCon cells, boasting multiple industry-leading properties. Compared to PERC modules, TOPCon modules exhibit superior attributes, including lower temperature coefficient and degradation, as well as higher bifaciality. Implementing solar systems utilizing CSI TOPCon modules can potentially reduce Balance of System (BOS) costs by nearly 2% and increase power generation by 2.3% over the 30-year performance warranty period.

CSI Solar 182 Plus TOPCon modules adopt rectangular silicon wafers and cells, with a module current of approximately 14.8A, perfectly matching the string current of 15A for inverters, reducing inverter power redundancy and lowering the Balance of System (BOS) and levelized cost of electricity (LCOE) of the photovoltaic system. The power of the 182 Plus 72-cell module reaches up to 620 watts, with dimensions of 2,382mm x 1,134mm, effectively utilizing the space within shipping containers and reducing module transportation costs. The module width is the same as that of conventional 182 modules, facilitating handling and installation.

Over the past decade, CSI Solar has been the first to mass-produce several new technologies in cells and modules, including five-busbar, multi-busbar, half-cell, double-glass, and bifacial cells and modules, leading the development direction of high-efficiency, high-power, and high-reliability modules. As of December 2023, CSI Solar has accumulated a total of 3,339 authorized patents, including 382 invention patents, covering areas such as silicon wafer processes and methods, cell structure, processes, and methods, module structure and methods, and related equipment, placing it at the forefront of the global photovoltaic industry.

In 2017, CSI Solar achieved a significant breakthrough by increasing the wafer size from 158.75×158.75mm to 166×166mm. This advancement led to the industry's first module power exceeding 400W, thereby catalyzing the technological trend toward larger-sized wafers and higher-power modules in recent years. In the era of N-type technology, CSI Solar remains steadfast in its commitment to technology-driven innovation, aiming to excel and introduce more advanced and impactful technologies to drive industry development forward.

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