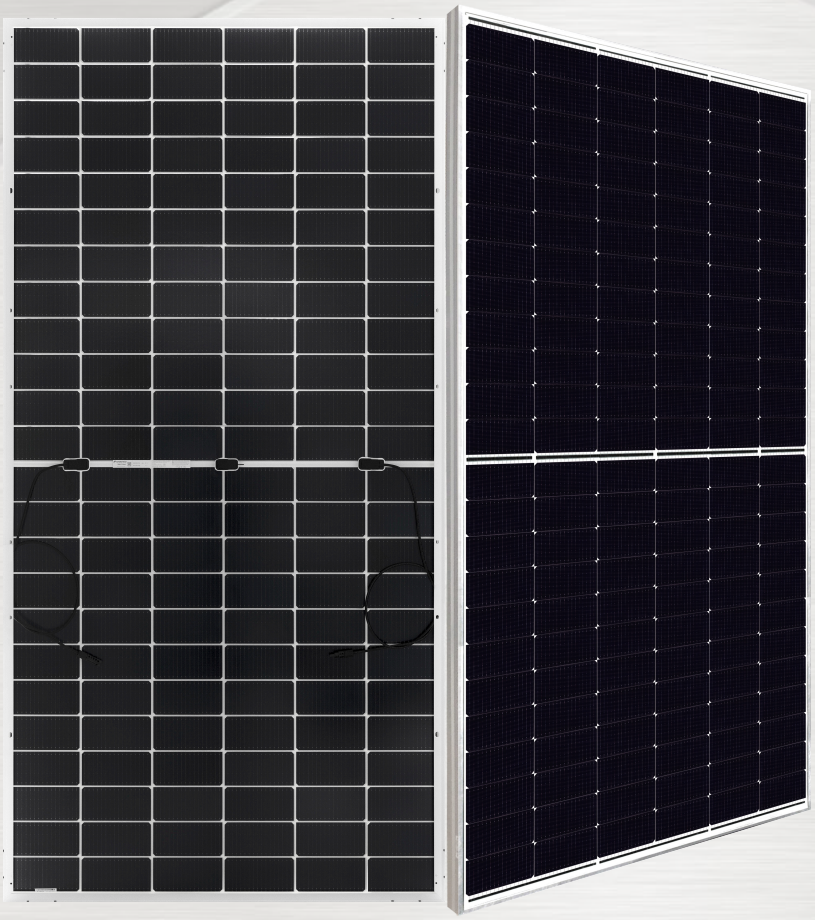
CanadianSolar



CSI High Efficiency TOPCon Module

White Paper

CSI Solar Co., Ltd

1.Introduction

Canadian Solar is one of the world's largest suppliers of solar photovoltaic modules, system solutions, and one of the largest solar power plant developers. By October 2022, Canadian Solar has shipped more than 80GW solar modules to customers in over 160 countries worldwide and owns a global portfolio of 25GW solar PV projects and 40GWh energy storage projects. CSI solar, the majority-owned subsidiary of Candian Solar, expanded its module manufacturing capacity to 32GW in 2022 and expects to reach 50GW module manufacturing capacity by the end of 2023. In 2022, Canadian Solar was again recognized as one of the most bankable PV module brands in the world by Bloomberg New Energy Finance.

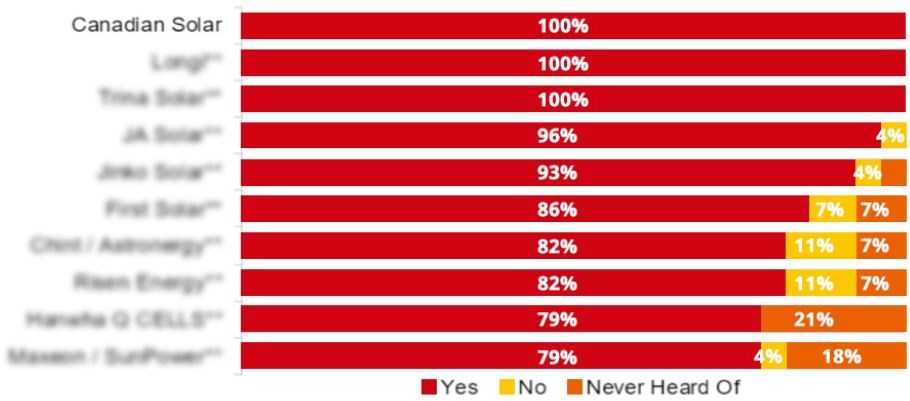


Figure 1. The world's top 10 most bankable PV module brands in BNEF's 2022 survey

CSI Solar focuses on continuously improving the performance and reliability of its solar modules and providing high quality products to customers, by actively exploring and introducing new cell and module technologies. CSI Solar was one of the first companies introducing cell and module technologies that later became industry mainstream, such as bifacial modules (back in 2010), modules with larger-format wafers (up to 210mm) and, nowadays, N-type high-efficiency cells and modules. Since 2019, CSI Solar has been developing N-type TOPCon (Tunnel Oxide Passivated Contacts) technologies, and now launches a diversified TOPCon module portfolio covering both 182mm and 210mm cells, single-glass and double-glass encapsulation, and various module sizes and power outputs to satisfy different application scenarios.

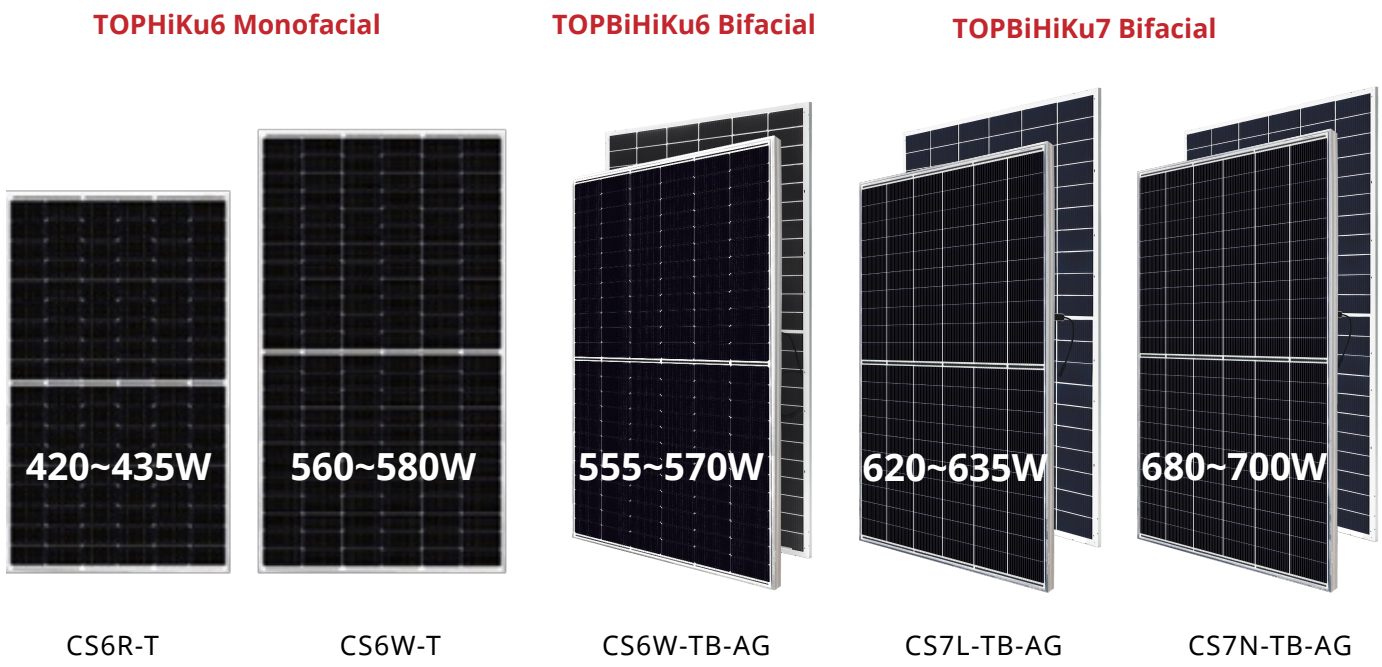


Figure 2. CSI TOPCon Module Family

First Solar Exhibit 2003, Page 2 of 11
Canadian Solar (USA) Inc. v. First Solar - IPR2025-01432

Module Power (W)	420~435	560~580	555~570	620~635	680~700
Module Type	CS6R-T	CS6W-T	CS6W-TB-AG	CS7L-TB-AG	CS7N-TB-AG
Module Efficiency	22.30%	22.50%	22.10%	22.40%	22.50%
Module Size (mm)	1722×1134×30	2278×1134×30	2278×1134×30	2172×1303×33	2384×1303×33

Table 1. Key Parameters of CSI TOPCon Modules

2.More Power, Higher Reliability – Advantages of CSI TOPCon Modules

The recombination of electrons and holes on the surface and any interface is the main factor limiting cell efficiency, and various passivation technologies have been developed to reduce the recombination, from early-stage BSF (Back Surface Field) to currently popular PERC (Passivated Emitter and Rear Cell), latest HJT (Heterojunction) and nowadays TOPCon technologies. TOPCon is an advanced passivation technology, which is compatible with both P-type and N-type silicon wafers and can greatly enhance cell efficiency by growing an ultra-thin oxide layer and a doped polysilicon layer on the back of the cell to create a good interfacial passivation. When combined with N-type silicon wafers, upper efficiency limit of TOPCon cells is estimated to be 28.7%, outclassing that of PERC, which would be about 24.5%. TOPCon's processing is more compatible to the existing PERC production lines, thus balancing better manufacturing cost and higher module efficiency. TOPCon is expected to be mainstream cell technology in the coming years.

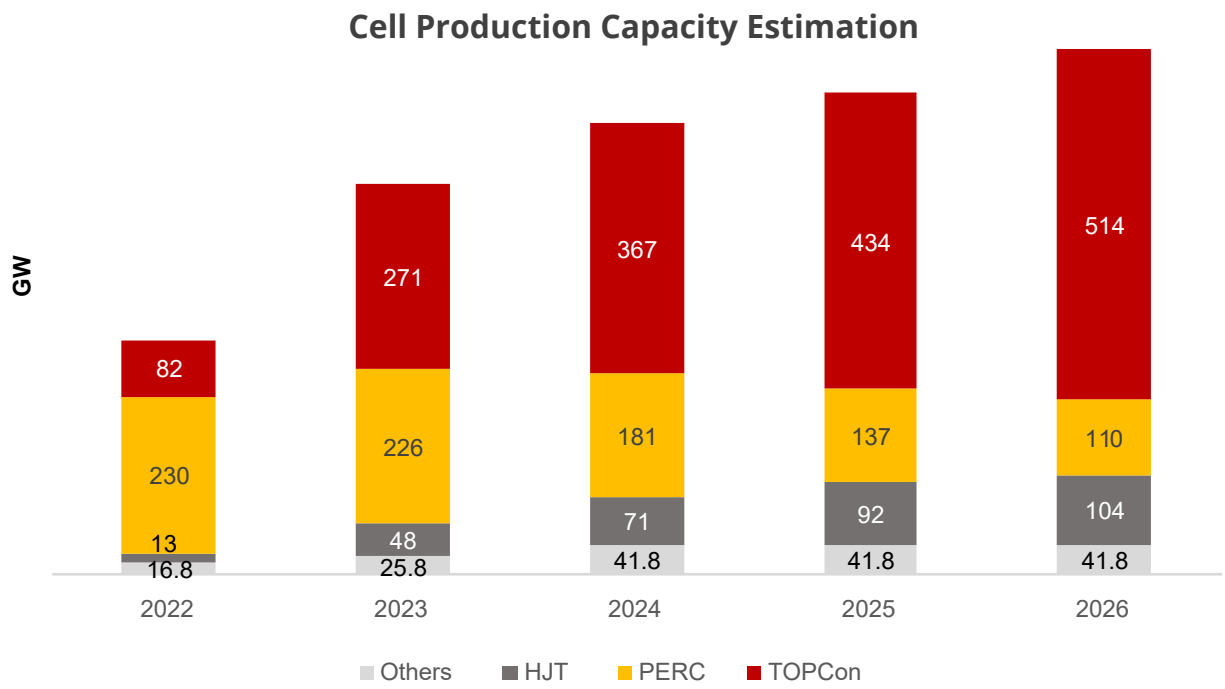
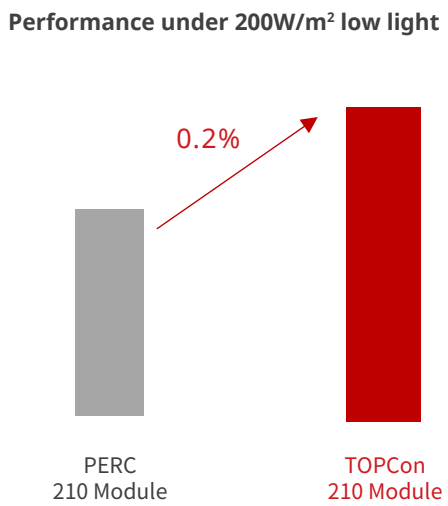


Figure 3. PV InfoLink Production Capacity Estimation

More specifically, CSI Solar has adopted the latest in-situ doping polysilicon deposition technology, efficient selective emitter (SE) technology, and backside multi-layer technology into TOPCon cells. These technologies can improve open-circuit voltage, short-circuit current by precisely controlling polysilicon film thickness, doping concentration of phosphorus and the PN junction profile. In addition, CSI R&D team have further optimized various parameters like surface optical reflection, series resistance, shunt resistance, front/ back finger design and silver paste consumption. With these efforts, cell efficiency and module performance have been improved significantly.

More Energy Yield under Low-light Environment

TOPCon modules enjoy better low-light performance. Improved low light performance is mainly related to the optimization of series resistance, leading to low saturation currents in TOPCon modules. Under low-light condition (200W/m²), performance of 210 TOPCon modules would be about 0.2% higher than 210 PERC modules .



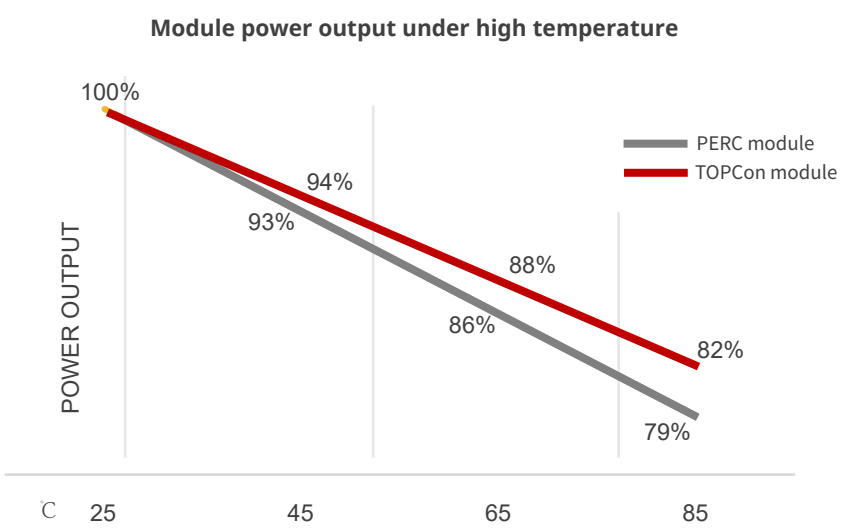
CSI TOPCon 210 module:

0.2% higher performance than PERC 210 module under low light

Figure 4. Low-light Performance Comparison

Better Power Output under High-Temperature Environment

Modules' operating temperature impacts their power output. CSI TOPCon modules are based on N-type silicon wafers with high minority carrier lifetime and higher open-circuit voltage. The higher open-circuit voltage, the better module temperature coefficient. As a result, TOPCon modules would perform better than PERC modules when operating in high temperature environments.



CSI TOPCon Module:

Higher power output under high temperature

Figure 5. Influence of module temperature on its power output

Advanced Manufacturing Technologies to Assure TOPCon Module Performance and Reliability

CSI N-Type TOPCon modules have been developed with excellence in both product design and reliable manufacturing technologies, including non-destructive cell dicing, precise soldering (Figure 6), and high-density stringing technology, which can assure modules' performance and reliability.

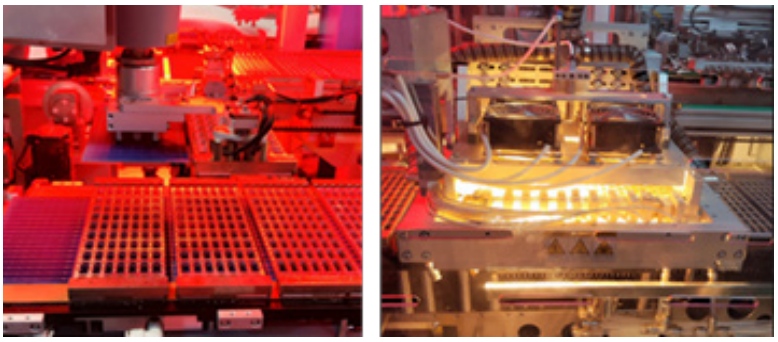
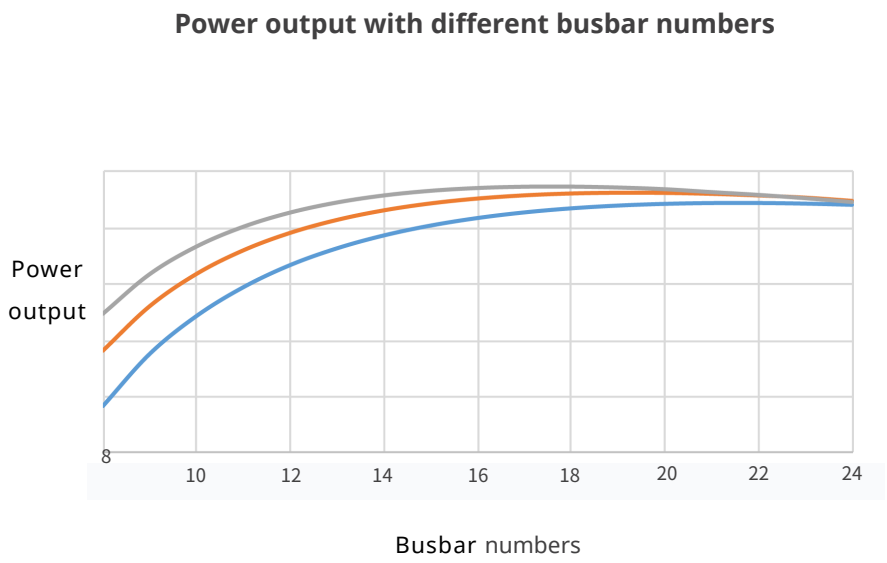


Figure 6. Non-destructive cell dicing and precise soldering for TOPCon modules

With advances of manufacturing technologies, CSI optimized the design of conductive silver fingers and busbar numbers in TOPCon cells. According to our simulation and verification, TOPBiHiKu7 series based on 210mm cells adopt 18 busbars, referred to as 18BB, and TOP(Bi)HiKu6 series based on 182mm cells adopt 16 busbars, referred to as 16BB.

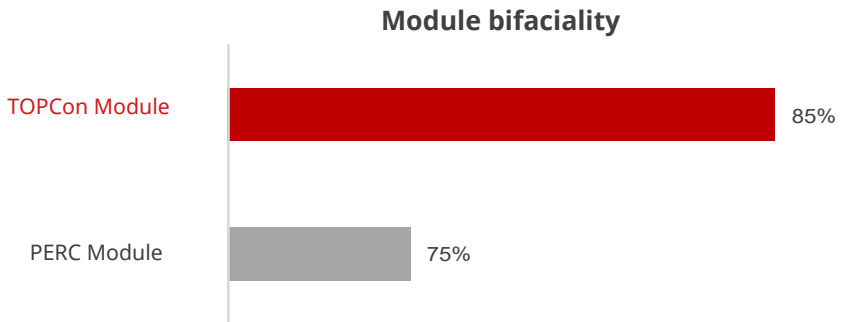


CSI TOPCon Module: SMBB cell technology, improves module efficiency

Figure 7. Power simulation of different busbar

Higher Bifaciality, More Power

Bifaciality of silicon solar cells depends on their electronic properties and architecture. The minority carrier lifetime of N-type silicon wafers is inherently higher, reaching more than 2ms. Meanwhile, symmetrical design on TOPCon cells' front and back sides allows TOPCon modules to have less shading area compared with PERC modules, so that TOPCon module's bifaciality is significantly increased. CSI N-Type TOPCon modules can see bifaciality up to 85%.



CSI TOPCon Module: Bifaciality up to 85%

Figure 8. Bifaciality of PERC and TOPCon modules

Industry Leading Extended Reliability Testing

CSI Solar 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.

Testing	IEC 61730/61215 Standard	CSI Standard
DH	1000 hours	2000 hours
TC	200 cycles	400~600 cycles
HF	10 cycles	20~30 cycles
PID	96 hours	192 hours

Table 2. Comparison of IEC Standard and CSI standard

Our test results show that TOPCon modules performed similarly or better compared with well recognized PERC modules.

For example, TOPCon bifacial modules showed less than 1% power degradation after DH 2000 test, which was much lower than 5% required by IEC standard after DH1000 test.

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/m^2, TOPCon cells showed about 0.2% less degradation compared to PERC cells.

CSI TOPCon Module: Better performance and lower degradation after testing

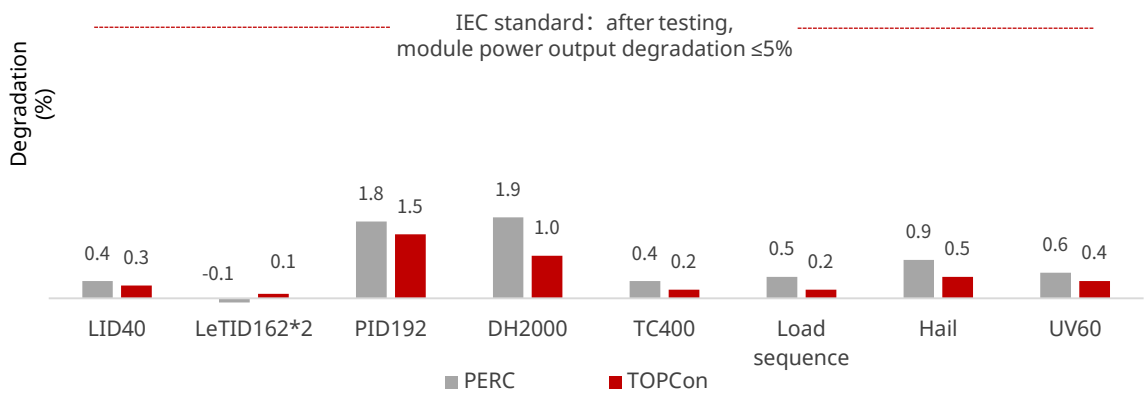


Figure 9. Reliability test results of PERC and TOPCon modules

Longer Warranty, Lower Power Degradation

Symmetrical design on the front and back sides of 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.

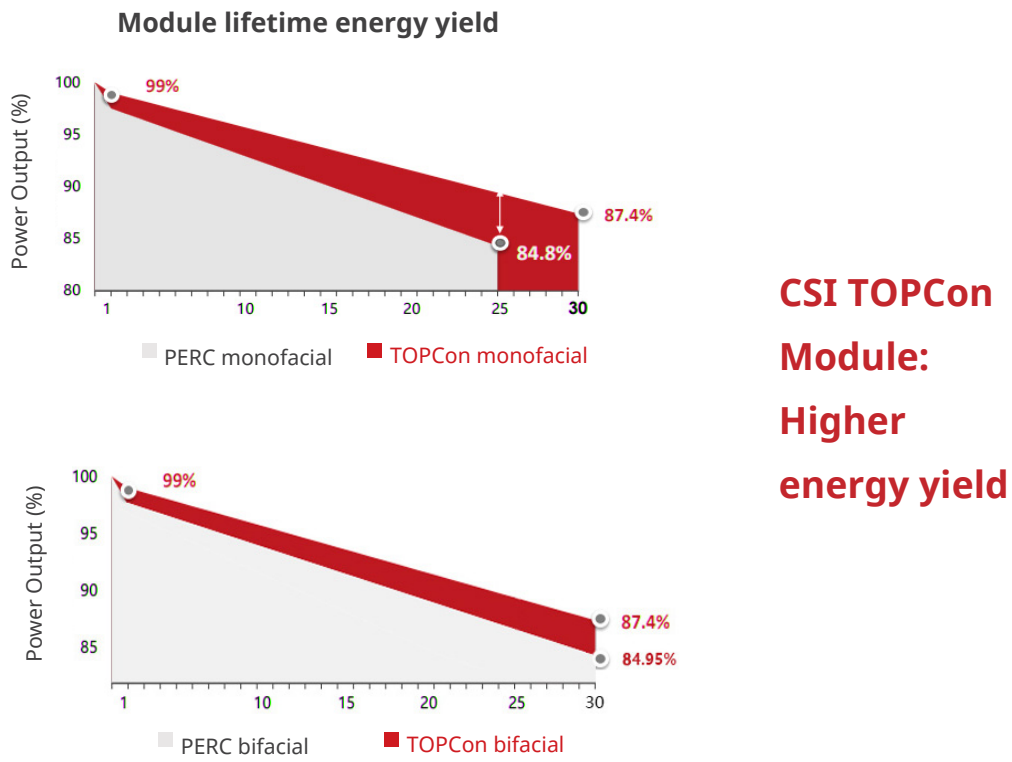


Figure 10. Lifetime power output of TOPCon and PERC modules

3. More Energy Yield, Lower System LCOE

More Energy Yield

In order to understand TOPCon modules' performance compared with PERC modules, we simulated system performance with CSI TOPCon (TOPBiHiKu7, 7N-TB-AG-685W) and PERC (BiHiKu7, 7N-MB-AG-660W) modules based on a 28.7MW solar farm assumed in Los Angeles, U.S.

Module	PERC Bifacial-660W	TOPCon Bifacial-685W
Power（W）	660	685
Module area(m2)	3.11	3.11
Module efficiency	21.20%	22.10%
Module Open-Circuit Voltage(V)	45.4	47.1
Annual Degradation Rate	0.45%	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	0.313	0.301
Pitch (m)	7.62	7.91
Module Number/String	31	30
String Number per rack	2	
Module Number per rack	62	61
Module Power per rack (W)	40,920	41,785
Length of rack (m)	83.4	80.8
Total Module Area per rack (m2)	192.6	186.4

Table 3. Parameters used in system performance simulation

Simulation results showed that energy yield of TOPCon modules would be about 2% higher than that of PERC modules during 30-year lifetime.

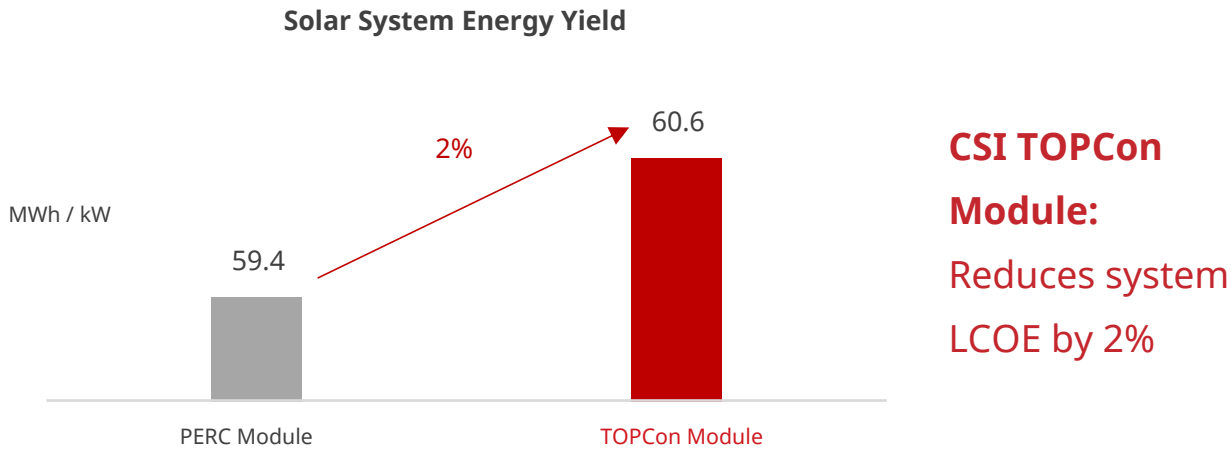


Figure 11. Comparison of energy yield between PERC and TOPCon bifacial modules

Lower BOS Cost

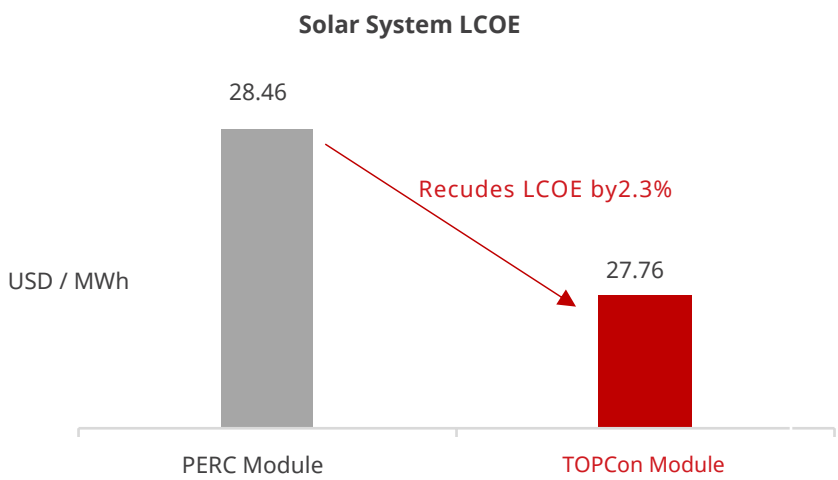
Due to higher efficiency of TOPCon bifacial module, less modules will be required for similar DC capacity. Subsequently, other costs for examples, installation and racks, will also be reduced, and the overall BOS cost is expected to decrease by about 1.1%.

Cost	PERC Bifacial-660W	TOPCon Bifacial-685W
Module Installation Cost	100%	96.30%
Rack Material Cost	100%	96.90%
Rack Installation Cost	100%	97.60%
Material and Installation Cost of Cable and Combiner Box	100%	98.80%
Development Cost	100%	99.20%
Total BOS Cost	100%	98.90%

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

Lower LCOE

Based on above simulation, we found that the LCOE of system using PERC bifacial modules would be about 28.46 US$/MWh, while the LCOE of system with TOPCon bifacial modules would be about 27.76$/MWh, about 2.3% less compared with PERC case.



CSI TOPCon Module:

Reduces system LCOE by 2.3%

Figure12. LCOE comparison between systems with TOPCon and PERC bifacial modules

Great System Compatibility

Canadian Solar 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 13. Mainstream rack manufacturers

As to 210 TOPCon modules with larger current, they are compatible with mainstream inverter brands, for examples, Sungrow, Solis, SMA, Huawei, etc.

Figure14. Mainstream inverter suppliers

Closing note:

With 22-year expertise in solar module business and well-recognized records, CSI Solar is always excited to be able to bring customers new products. With superior performance and quality assurance, CSI N-Type TOPCon modules will bring customers lower cost of electricity and higher return on investment, help contributing to global energy transformation and creating more sunny future together with our customers.

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