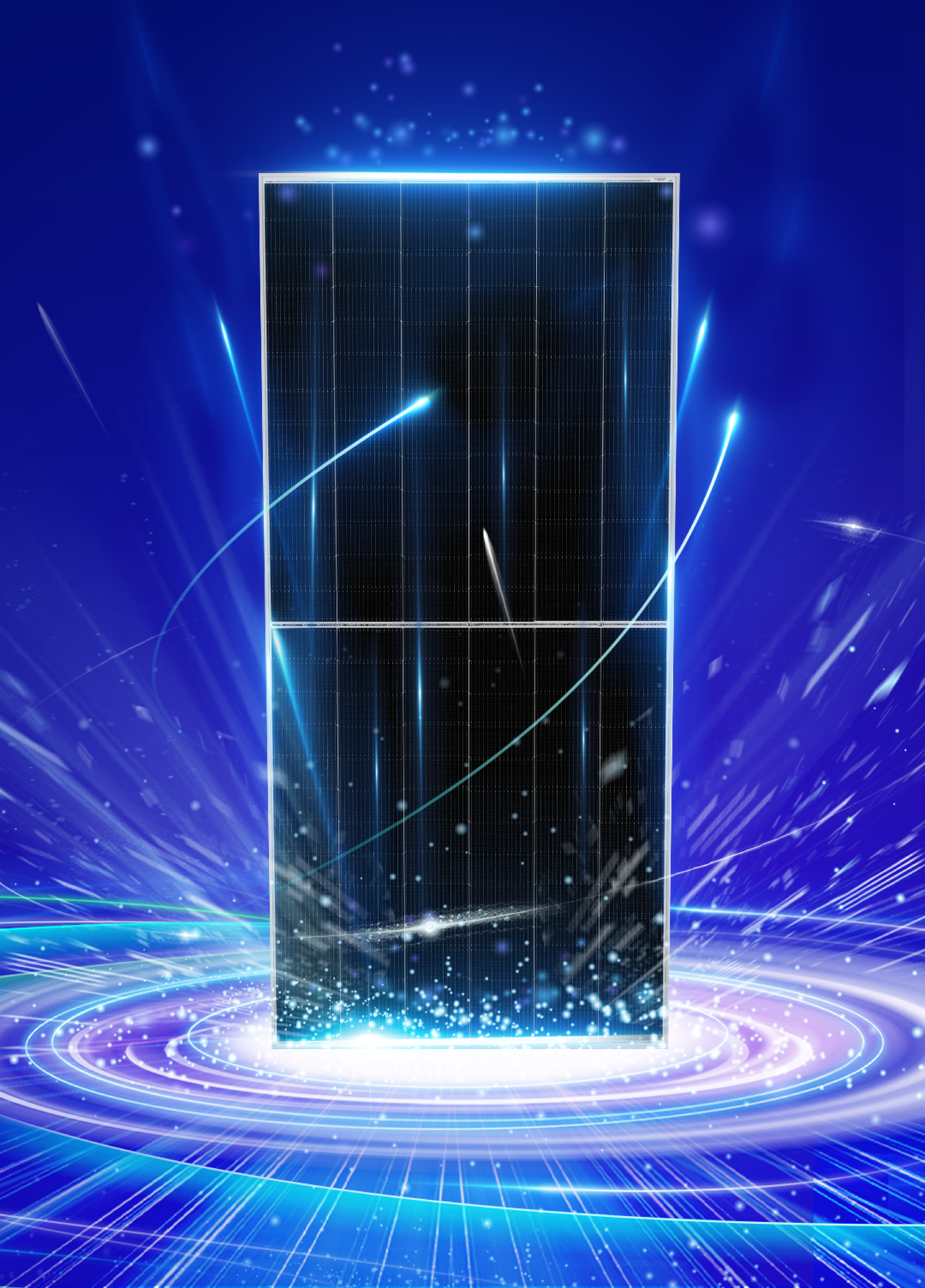
JA SOLAR | DEEP BLUE 4.0

DeepBlue 4.0 X

Technical White Paper



01 | Background

1.1 PV module development trends

With decades of development, PV power generation is now an important part of the global energy infrastructure, transforming it from an emerging industry into a mature industry. As the core unit of PV power generation, the module has experienced profound technical change during these years of development. No matter the type of improvement, these changes are responsible for the primary trends of better quality and efficiency, which are two aspects of product performance that impact each other and are inseparable. Unlike traditional consumer electronics, PV modules sport a lifespan of at least 25 years or longer, so the primary evaluation criteria revolve around ensuring continuous, reliable, and high efficiency power generation. Success in this effort is measured by LCOE and this is the core value to the customer.

As PV products improve, to ensure high quality the reliability tests are becoming more comprehensive and strict. To meet various new and modified standards, PV equipment manufacturers need constant new technology research and development, which includes the introduction of new materials, new processes, and new products. To properly evaluate reliability, stability and overall power generation performance, modules must be verified by outdoor field tests in a variety of climatic conditions.

Module efficiency improvements naturally reduce BOS cost of PV systems, and thus reduce LCOE. The industry has improved module efficiency mainly through better cell efficiency and module encapsulation. The efficiency improvement path is shown in Figure 1. After 2016, with the large-scale introduction of PERC cell technology into mass production, module efficiency was increased from ~16% to ~21% by combining half cell technology, MBB technology, SE technology and various high-efficiency BOM materials. In 2022, as PERC cells reached the peak efficiency of mass production, TOPCon and HJT cells picked up the baton to drive improvements. TOPCon cells have taken the lead in achieving large-scale production due to the high compatibility between TOPCon cell preparation process and PERC cell production line, large cell efficiency improvement potential and lower equipment investment cost. Module mass production efficiency should reach more than 22%.

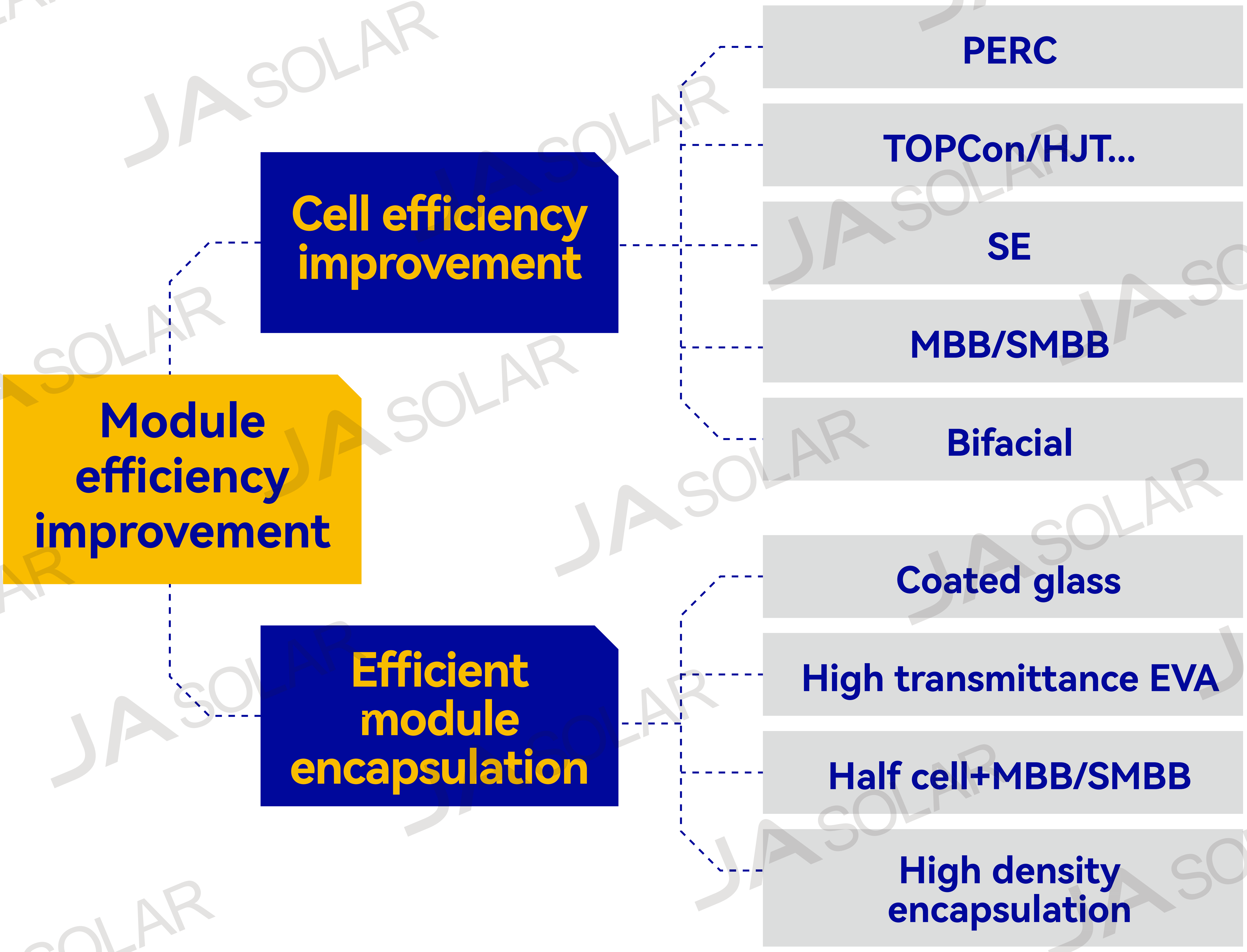


Figure 1 : The main efficiency improvement path of PV module

1.2 JA Solar DeepBlue product design concept

Technical innovation is the foundation of JA Solar's development effort. Starting in 2020, JA Solar stepped up its product R&D investment and launched the DeepBlue 3.0 series of high efficiency modules, based on its M10 wafer and Percium+ cell technology. DeepBlue 3.0 modules have been unanimously recognized and praised by users and third-party organizations in many countries. Following the product strategy of "generation of production, generation of reserve and generation of R&D", over 10 years ago JA Solar recognized the efficiency limit of p-type cells started research and development on n-type cells and modules. After many iterations and repeated validation, JA solar launched the n-type high-efficiency series modules called DeepBlue

4.0 X in May 2022, whose mass production power can reach 625W. The DeepBlue 4.0 X tagline is “DeepBlue, tailored to increase customer value", which is lived out in the product’s continuous improvement in quality and performance, thus bringing customers lower LCOE, higher product value and a better customer experience.

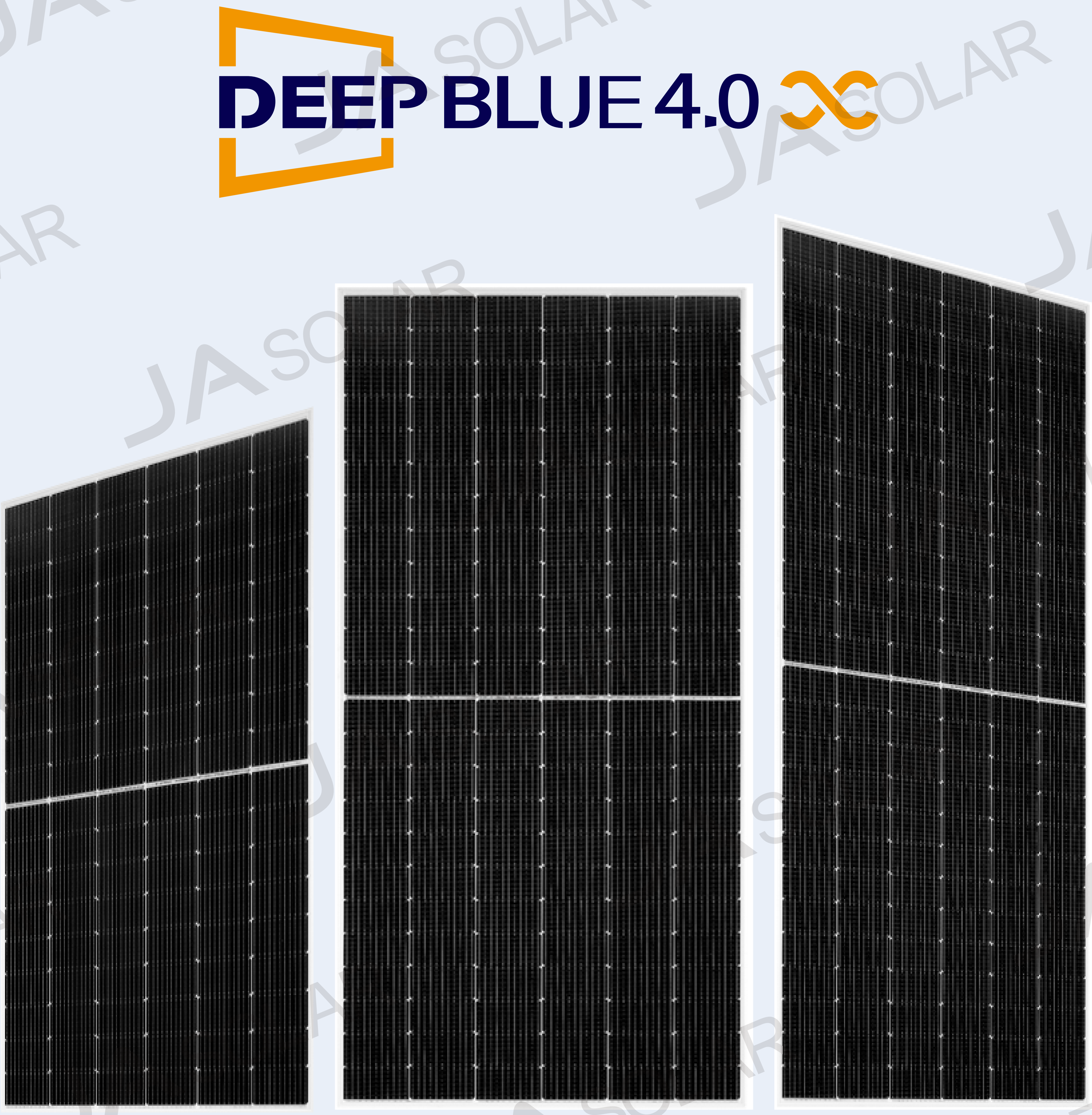


Figure 2 : DeepBlue 4.0 X series products

02 | Core technology

The DeepBlue 4.0 X module adopts two core technologies: an n-type Bycium+ cell and Gapless flexible interconnection (GFI) technology. In addition, DeepBlue 4.0 X utilizes the improving quality and efficiency technologies of the earlier DeepBlue series of products, including M10 (182mm) silicon technology, MBB technology, half-cell technology. This effectively improves module conversion efficiency while ensuring module stability and reliability.

2.1 Bycium+ high efficiency solar cell

Bycium+ cell is JA Solar's proprietary high efficiency n-type passivated contact cell, which is based on a mature 182mm size wafer, millisecond level low oxygen n-type wafer technology, optimized passivation and contact technologies, ultra-thin busbar metallization and double-sided anti-reflection film technology. The Voc of the cell can reach 720mV and the mass current production cell efficiency can reach 25%. The Bycium+ cell structure diagram is shown in Figure 3.

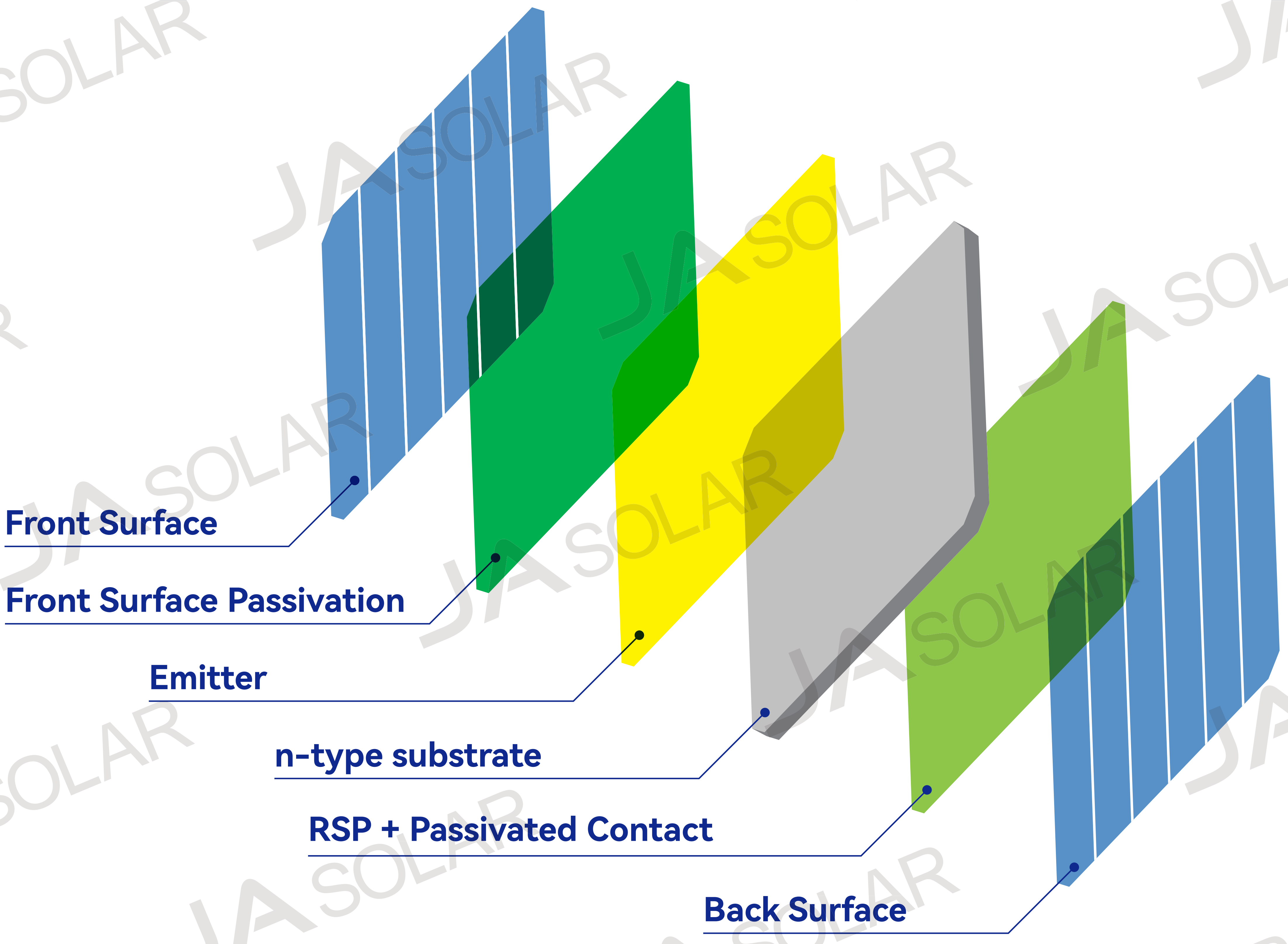


Figure 3 : Bycium+ cell structure diagram

2.2 Gapless flexible interconnection (GFI) technology

Module efficiency is improved both by better cell efficiency and high-density module encapsulation. The DeepBlue 4.0 X module adopts JA Solar's patented high-density module encapsulation technology: gapless flexible interconnection (GFI). The round ribbon has a special buffer treatment that handles mechanical stress at cell interconnections and thus eliminates the risk of micro-cracks. Meanwhile, JA Solar maintained the standardized size of the modules by adjusting the size of the silicon wafers, which ensures versatility for downstream applications.

GFI technology is compatible with current mainstream module encapsulation technology, so that module efficiency can be increased by about 0.4% and module power can be increased by about 10W. Compared with conventional modules, GFI modules can reduce the project construction cost by 0.23cent/W to 0.38cent/W and lower LCOE by 0.3%-0.7%. System cost comparison data is shown in Figure 4.

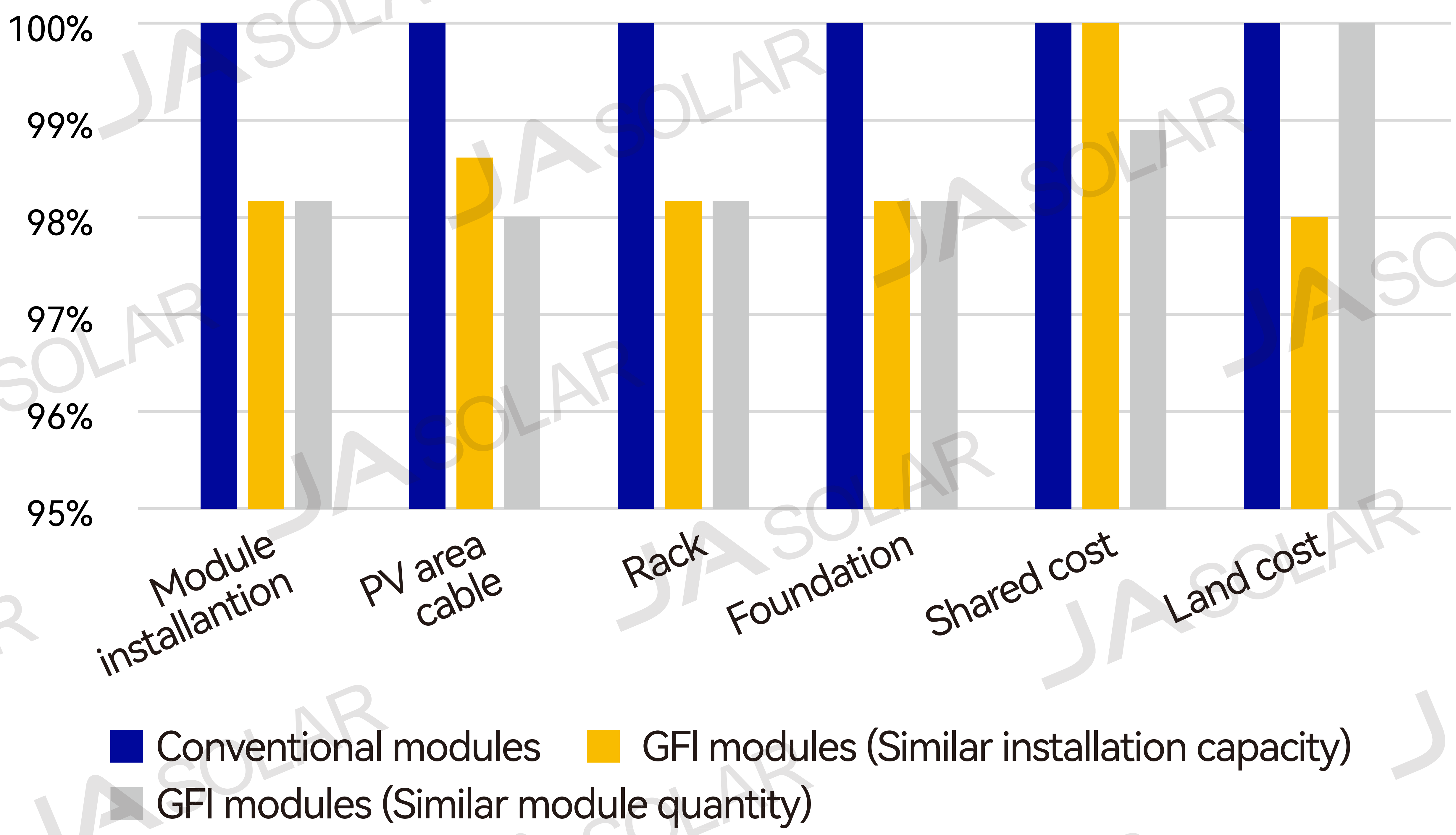


Figure 4 : The system cost comparison data

03 | Product advantages

DeepBlue 4.0 X module delivers strong power generation performance due to four characteristics created by its two core technologies: lower degradation, superior high temperature energy yield performance, higher bifacial generation gain and excellent low irradiance energy yield performance.

3.1 Lower degradation

Power degradation is reduced due to the natural advantage of n-type wafers (without B-O complex) in LID-free and better LeTID performance compared to conventional PERC cell. JA Solar offers a 30-year linear power output warranty with less than 1% degradation in the first year and less than 0.4% annual degradation in the following years. Calculations show power generation gain in the service lifetime to be up to

1.8% and first-year degradation data shows power gain of up to 1%, as shown in Figure 5.

A one-year field test performed by JA Solar and TÜV NORD shows that the first year power degradation of the n-type module based on Bycium+ cells is about 0.15%, which is considered by the industry to be excellent degradation performance.

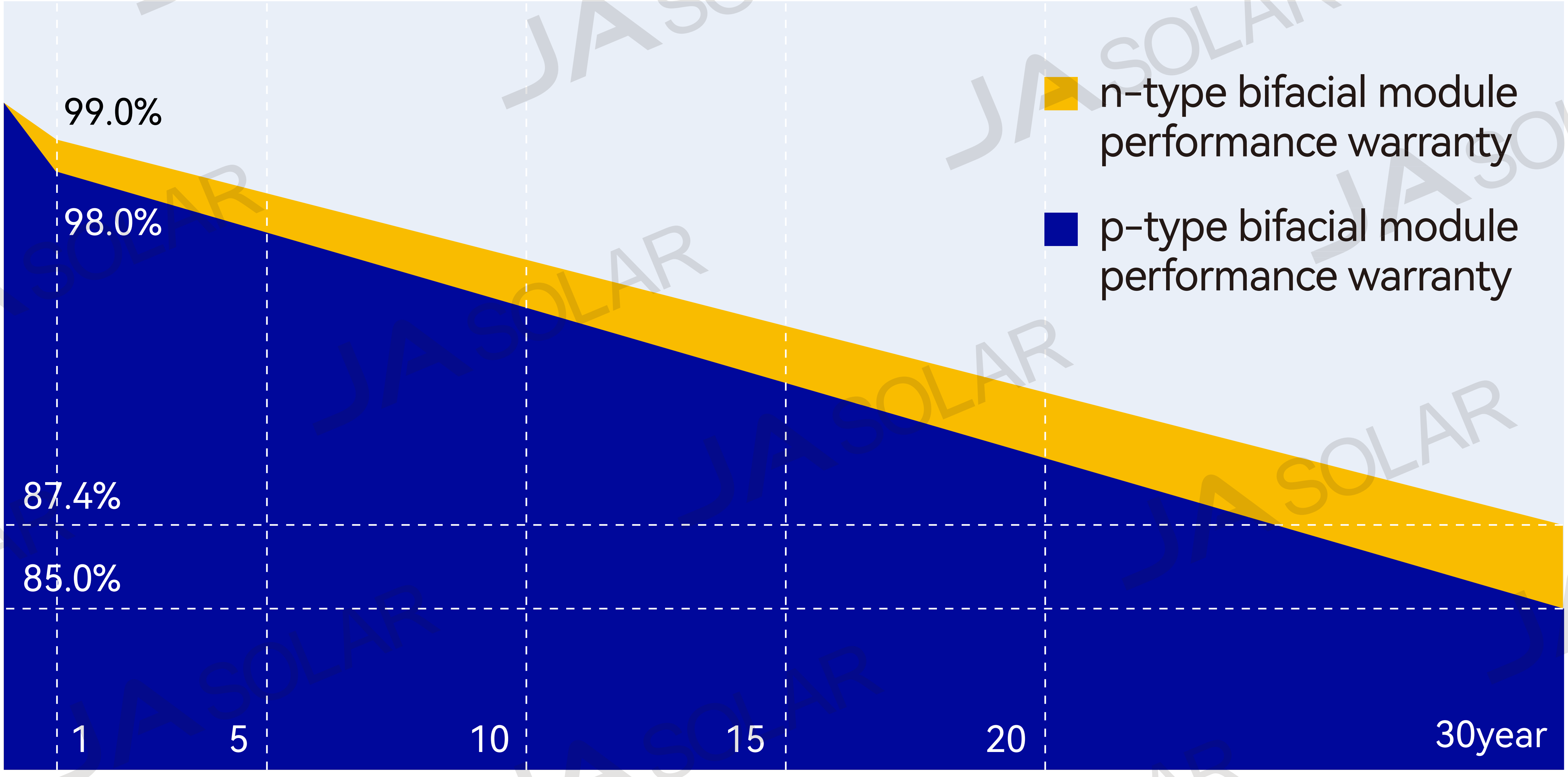


Figure 5 : Power Degradation of n-type and p-type modules

3.2 Superior high temperature energy yield performance

Looking at high temperature energy yield performance, which is driven by the temperature coefficient and module operating temperature, higher cell open voltage means a better theoretical temperature coefficient. The open-circuit voltage of an n-type Bycium+ cell can reach 720mV, with a temperature coefficient of -0.3%/℃, while p-type PERC is -0.35%/℃. During hot weather days, assuming module operating temperature is 55℃ (ambient temperature 30℃), n-type module power degradation loss is 1.5% lower than a p-type module in similar high temperature conditions. With module operating temperature continually increasing, the high temperature performance of an n-type module will be significantly better.

Due to the higher conversion efficiency of the n-type module, the heat conversion of the absorbed light energy is correspondingly reduced, thereby reducing the working temperature of the module. The JA Solar and TÜV NORD one-year field test fully confirms this, and Figure 6 shows that the average operating temperature of the n-type module is about 1°C lower than that of the p-type module. Due to the better temperature coefficient and lower operating temperature, the power generation of the n-type module based Bycium+ cells can be about 2% higher than that of the p-type PERC module.

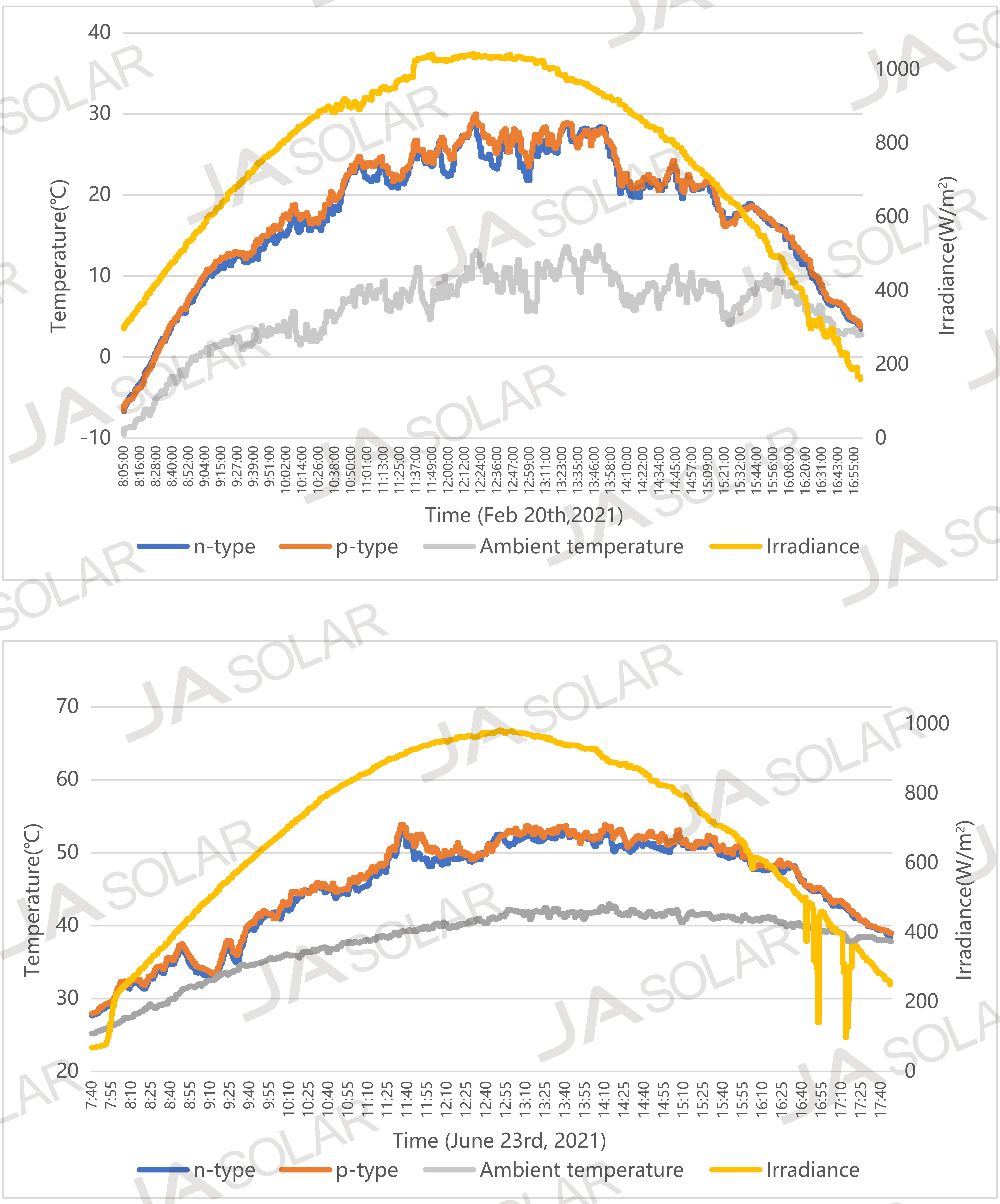


Figure 6: Operating temperature comparison of n-type and p-type PERC modules

3.3 Higher bifacial generation gain

Regarding bifacial generation performance, the n-type module has 80% bifaciality, which is much higher than the 70% of p-type PERC modules. Assuming irradiance under the rear side is 100~150 W/m^2 condition, the 10% bifaciality difference can result in a power gain of 1%-1.5% for the n-type module. Under different ground conditions (ground albedo between 20% and 30%) and depending on rack heights, front rack and back rack spacing, with or without shadow, the PVsyst simulation shows that the DeepBlue 4.0 X module generates power gains between 0.8% and 1.2%.

3.4 Excellent low irradiance energy yield performance

Theoretically, DeepBlue 4.0 X performance is highlighted mostly by shorter carrier lifetime, open-circuit voltage, and sheet resistance in low irradiance energy yield performance. Due to Bycium+ cells better internal resistance design, higher minority carrier lifetime and open-circuit voltage, the cell's low irradiance performance is superior. Under 600W/m² conditions, like in the morning or night fall, simulation shows the n-type energy yield gain to be about 0.2%.

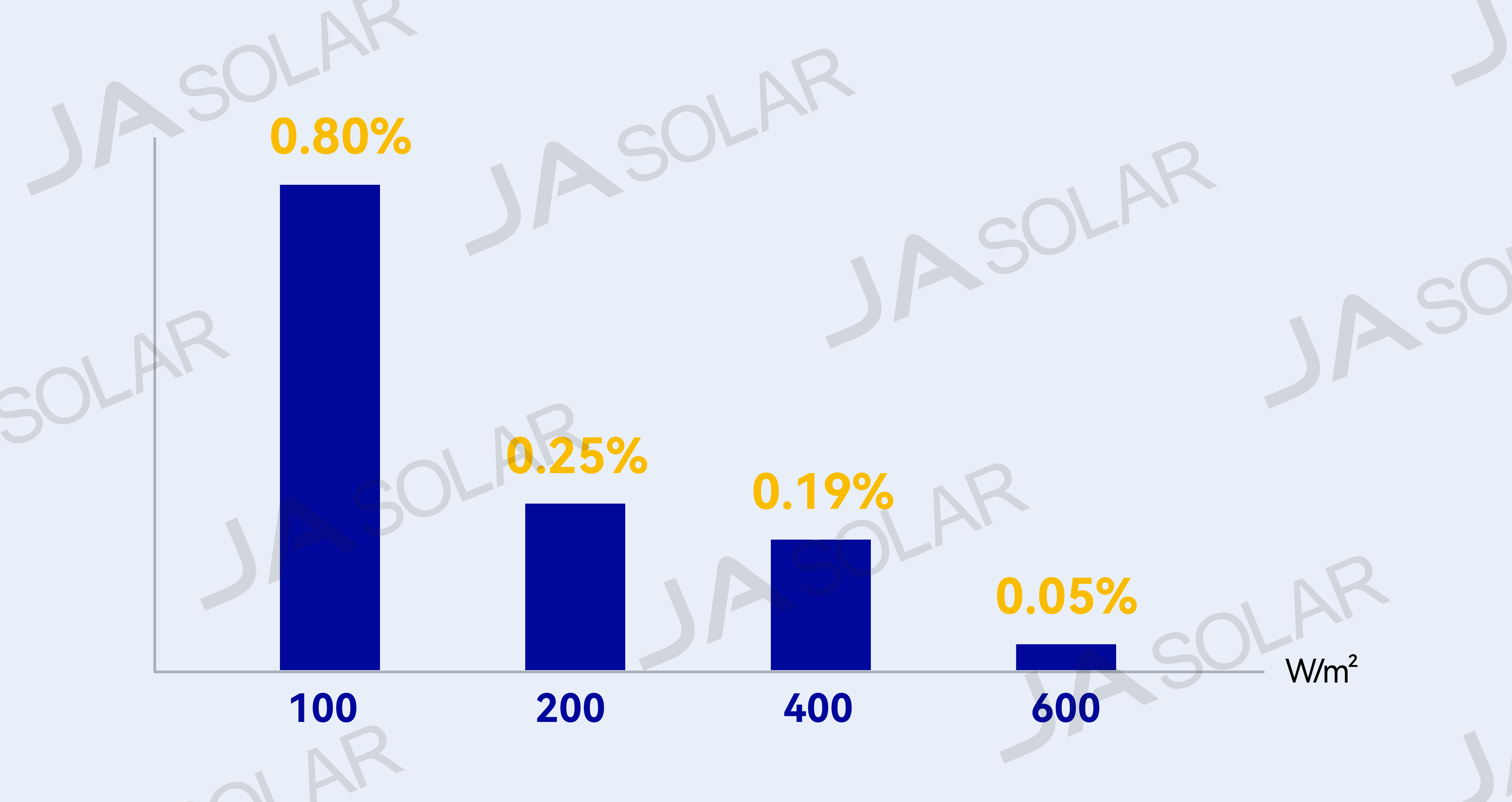


Figure 7: DeepBlue 4.0 X module low irradiance power generation gain

04 | Excellent reliability

Module reliability is commonly verified by accelerated aging tests in the laboratory. DeepBlue 4.0 X modules have excellent reliability like all the modules in the DeepBlue series. The DeepBlue 4.0 X modules have passed the standard aging test and intensified aging test to meet IEC standard requirements and exemplifies the module's outstanding performance. Test results are shown in Figure 8.

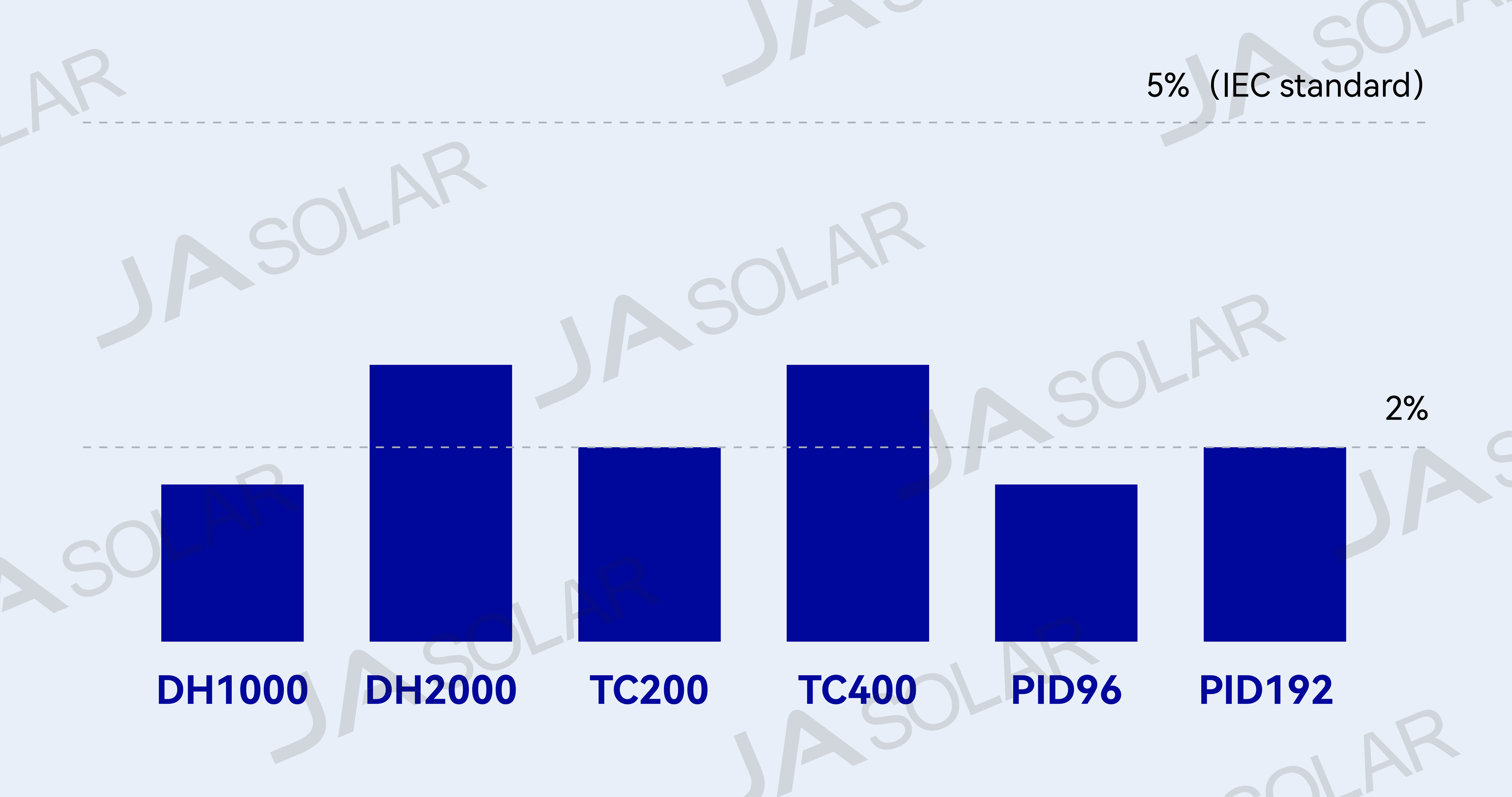


Figure 8: DeepBlue 4.0 X module reliability test results

05 Product parameters and application scenarios

DeepBlue 4.0 X module mainly includes three-dimension designs: 54-cell, 72-cell, and 78-cell. Main technical parameters are shown in Table 1, with modules categorized for different applicable scenarios as: 54-cell module for residential PV systems, 72-cell and 78-cell modules for commercial and industrial projects and utility-scale PV projects.

Table 1: DeepBlue 4.0 X module main technical parameters

Module type/ technical parameters	JAM54D40 -430/GB	JAM54D40 -435/GB	JAM72D40 -570/GB	JAM72D40 -575/GB	JAM78D40 -620/GB	JAM78D40 -625/GB
Pmax [W]	430	435	570	575	620	625
Vmpp [V]	32.21	32.42	42.70	42.85	46.20	46.37
Impp [A]	13.35	13.42	13.35	13.42	13.42	13.48
Voc [V]	38.32	38.45	51.00	51.15	55.34	55.49
Isc [A]	14.23	14.30	14.23	14.30	14.30	14.36
Module efficiency	22.0%	22.3%	22.1%	22.3%	22.2%	22.4%
Temperature coefficient of Isc	+0.046%/℃					
Temperature coefficient of Voc	-0.260%/℃					
Temperature coefficient of Pmax	-0.300%/℃					
Dimensions	1722mm*1134mm*30mm		2278mm*1134mm*30mm		2465mm*1134mm*35mm	
Weight	21.5kg		31.8kg		34.6kg	
Warranty	1% 1st-year degradation, 0.4% annual degradation over 30 years					

06 | Customer value

LCOE is a core measure of customer value. Modules with high power, high efficiency, high energy generation capacity, and high reliability can bring customers more value with improved overall revenue.

The JA Solar and TÜV NORD one-year field test (at the CPVT National Photovoltaic Experimental Base in Yinchuan, China) showed that the energy yield of the n-type module based on Bycium+ cells is 3.9% higher than that of p-PERC module. The power generation comparison data is shown in Figure 9. The n-type module's theoretical power generation is at about 4%, due to lower degradation, superior high temperature energy yield performance, higher bifacial generation gain, and excellent low irradiance energy yield performance. This number is consistent with field test data and publicly available industry statistics.

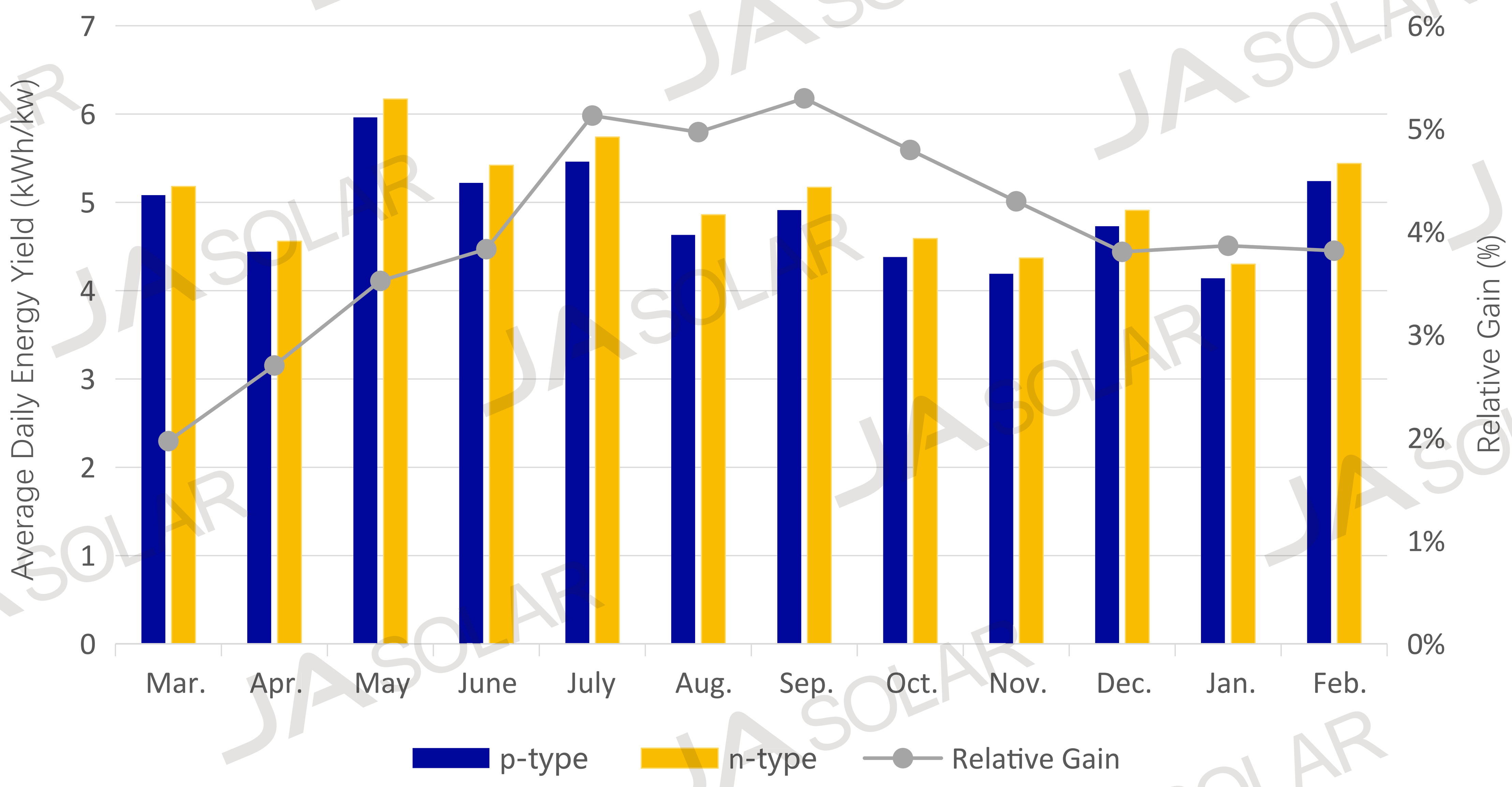


Figure 9: Comparison data between n-type module and p-type PERC module

For example, by examining the cost of the 100MW project in Dubai—taking into consideration the cost of rack, foundation, cable, installation, and land area-- DeepBlue 4.0 X modules can reduce the BOS cost by 2.1% and LCOE by 4.6%. At the same time, the LCOE can be reduced by about 3.5-5% depending on global region, climatic conditions, and project, as shown in the figure 10.

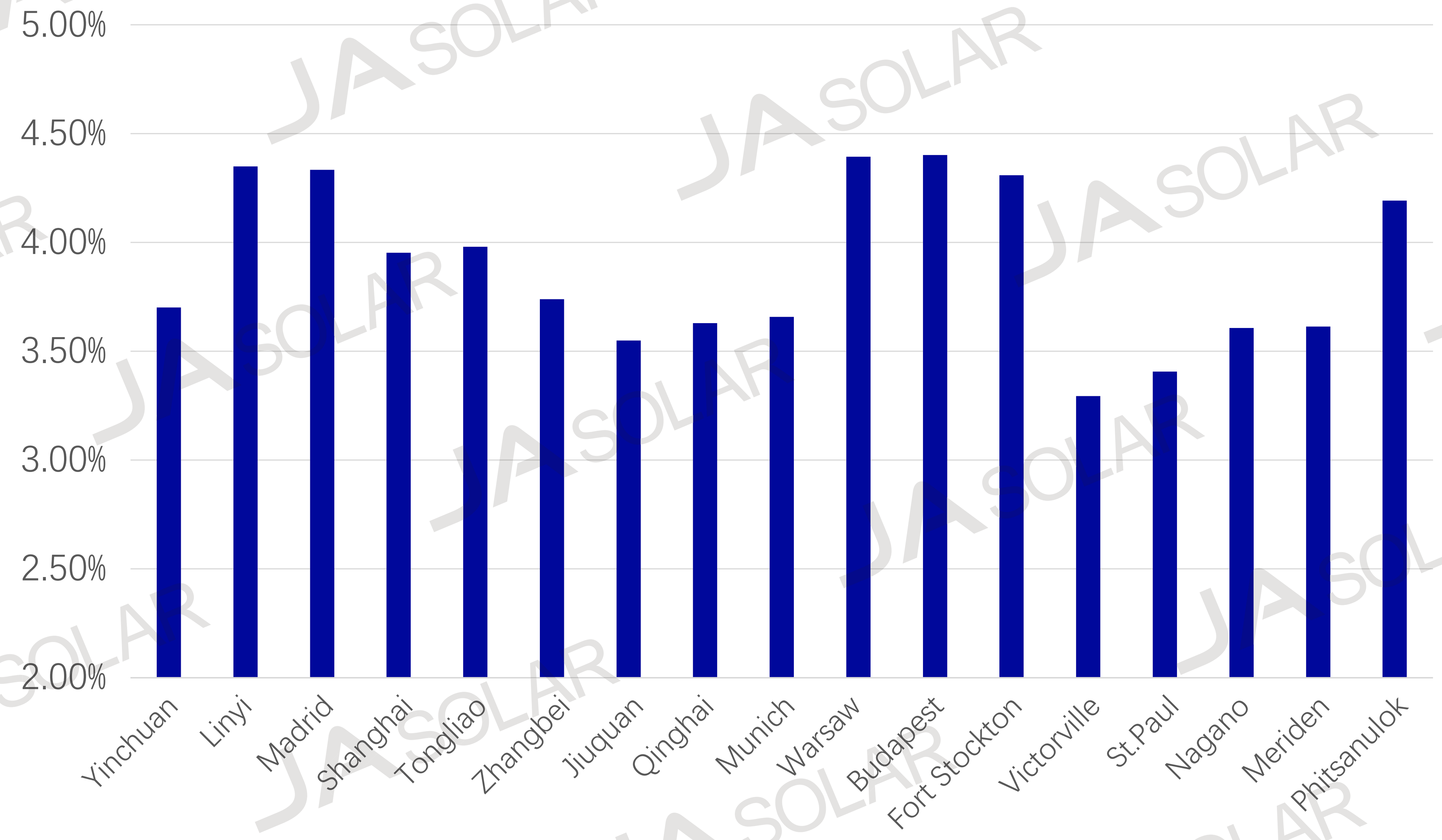


Figure 10: System cost calculation data

CUSTOMER VALUE

As the core indicator to measure the power generation of photovoltaic projects, LCOE is closely related to the core value focused on by the end customers. Among the factors directly affecting LCOE, those related to modules mainly include the power, efficiency, power generation capacity and long-term application reliability of modules. Specifically, high power and high efficiency can effectively reduce the cost of BOS, and power generation capacity and long-term application reliability is conducive to the efficient and stable power generation of products in the full life cycle. Paying attention to customer value and focusing on improving customer value all the time, JA Solar launched DeepBlue series products that integrate high power, high efficiency, high power generation capacity and high reliability, which truly explains the product design concept of “DeepBlue, tailored to increase customer value”.