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Back Contact (BC) Solar Technology Development

White Paper

Abstract

1. Core Objectives and Value Propositions of the White Paper

Core objectives:

At the key node of intergenerational transition of global Photovoltaic (PV) technology, the back contact (BC) cell technology is leading the new-generation PV technology paradigm revolution, becoming the core engine to drive industry cost reduction and efficiency improvement and realize energy transition. This White Paper is intended to systematically analyze the industrialization breakthrough path and application value of BC technology, so that the PV industry, from industry participants to power station investors, can clearly recognize the technological advantages and development status of BC products, provide technical support for industrial investment, power station design and module procurement and selection, accelerate the large-scale application of BC technology, and inject deterministic momentum into the global energy transition.

Value propositions:

BC is the only way for the development of PV technology: The current BC cell mass production efficiency exceeds 27% which is 1.6% higher than TOPCon(tunnel oxide passivated contact), technology maturity and cost competitiveness have been close to the traditional technology; its theoretical efficiency limit of 29.1% infinitely approaches the theoretical ceiling of crystalline silicon efficiency; BC is the only technology carrier that can cross the "29%+" threshold, and is thus the only way for all technologies to continue developing efficiently.

The advantages of BC technology have been fully verified: The high efficiency, high power generation capacity and higher reliability of BC technology have been fully verified by authoritative third-party testing and outdoor applications.

Full life cycle value has been highlighted: In the current situation, BC technology has obvious investment value advantages in all PV power station scenarios in the world. With the continuous technological progress and cost reduction, BC technology will become the preferred choice for customer investment in all PV power station scenarios.

BC technology shows great potential for sustainable development: As global investment in photovoltaic power stations increasingly focuses on the carbon footprint of modules, the high-efficiency and low-carbon characteristics of BC technology will gradually enhance its competitive edge. In the future, whether it is the rapid improvement of short-term BC efficiency or the development of long-term stacked modules, BC technology has great development potential, ensuring the long-term rapid development of the technical route.

2. Key Innovation Points and Market Positioning of BC Technology

Technological breakthroughs:

Optical gain: in BC modules, both the positive and negative electrodes are on the backside of the cell, and the frontside has no metal busbar that shades light, so light absorption efficiency increased by 3-5%; the frontside does not have any busbar contact, and there is no pyramidal texture damage caused by high temperature steps, which improves the textured surface effect of frontside and the greatly reduces the front light reflectance to 1.5%. The absence of a doped layer on the front side eliminates photon parasitic absorption, enhancing photon utilization efficiency.

Electrical gain: through interdigitated electrode design and stack coating optimization, carrier recombination efficiency is greatly reduced, and carrier lifetime is effectively improved to more than 5 ms.

Reliability improvement: the full-backside monofacial soldering plus zero busbar (0BB) technology will improve the outdoor load and high/low temperature reliability of the module products, better prevent the risk of module microcrack; the cell equivalent bypass diode technology will reduce the localized overheating temperature in shaded condition by more than 30%, effectively protect the module products during normal operation in shaded condition and prevent fire.

Platform compatibility: With the continuous research and development of BC as a platform technology and its integration with other traditional technologies, the current technological integration of BC with TOPCon (TBC) and HJT (HBC) has been very mature, and the perovskite stack technology can also be seamlessly integrated in the future.

Mass production process breakthrough: Laser patterning process replaces traditional photolithography technology, equipment cost is reduced by more than 60%, and with the upgrading of laser technology, single-line production capacity is increased by more than 5 times; wet process optimization greatly shortens process steps to further improve manufacturing feasibility.

Market positioning:

Full-scenario market alternative technology: With the rapid decline of BC cell mass production cost, the technical value of BC modules in the whole scenario has been higher than the market price difference between BC modules and TOPCon since 2024, allowing the optimization of full-scenario value and rapidly promoting technology transition. It is estimated that the global market share will exceed 60% by 2030.

Preferred option in high investment scenario market: in the floating PV projects, offshore PV projects and the regional with high land cost and high labor cost, BC product value advantage is particularly prominent, and from the initial investment cost to the life cycle, its value is much higher than TOPCon modules, and it has become the preferred option given the current market value.

3. Quick Overview of Core Conclusions of Third-party Reliability Verification

After a large amount of test data analysis by authoritative third parties, the average reliability test results of BC modules are completely superior to those of TOPCon modules, which provides laboratory verification support for more stable electricity generation performance and safety reliability of BC modules in the whole life cycle. The authoritative test data are as follows:

Testing institution	Test item	Test standard	BC module performance	BC VS TOPCon module	Margin of advantage
TÜVRheinland® Precisely Right.	TC200	IEC 61215 (-40°C↔85°C)200 cycles	Degradation 0.53%	Degradation 0.63%	+15.8%
	DH1000	IEC 61215 (85°C/85%RH)1,000 hours	Degradation 1.21%	Degradation 1.31%	+7.6%
	PID 96h	IEC62804 (85°C/85%RH) 96 hours	Degradation 0.92%	Degradation 1.07%	+14%
	LID	IEC 61215-2 (60kWh)	Degradation 0.04%	Degradation 0.51%	+90%
	Sequence test (UV+DML+HF+TC)	/	Degradation 1.02%	Degradation 1.14%	+10.5%
TÜV SÜD	Wind tunnel ultimate load	Limit wind velocity test	Passed 64.4m/s wind tunnel test (equivalent to scale 18 super wind)	/	/
TÜVRheinland® Precisely Right.	NMOT	IEC 61853-1	41.1°C	41.6°C	0.5°C
	Hot spot	IEC 61215-2:2021 MQT 09 (hot spot test)	Average 138.1°C	Average 184.6°C	Lower than 40°C

4. Quick overview of empirical conclusions of BC's power generating capacity

Since the commencement of BC module mass production, Aiko Solar and LONGi have collaboratively established over 30 field demonstration projects worldwide with third-party partners and end customers, covering different application scenarios, including centralized and distributed systems, various climate conditions, and different ground reflectance levels, systematically validating the technology's real-world power generation performance. Due to the superiority of BC modules in temperature coefficient, IAM, low light performance and operating temperature compared with TOPCon modules, BC modules have more than 1.2% electricity generation compared with TOPCon technology in all-scenarios demonstration:

Empirical type	Shaded type	Empirical locations	Application scenarios	Empirical performance
Distributed project	No shading	Madrid, Xi'an, Nanjing	Flat roofs, colorful steel tiles	1.2%-2.8%
Utility project	No shading	Hainan, Shandong, Ningxia, Jiangsu, Guangdong	Water surface, floating, desert, grassland	1.4%-3.2%

Due to the shadow resistance capability of BC modules, global demonstration results show that the electricity generation gain of BC modules is between 4%~33% compared with TOPCon modules in shaded condition.

Empirical type	Shaded type	Empirical locations	Application scenarios	Empirical performance
Distributed project	Building, dust, etc. shading	Japan, Guangdong, Fujian, Jiangsu, Ningxia	Flat roofs, colorful steel tiles	4%-11%
Utility project	Column shading, bird droppings, dust, etc. shading	Hainan, Ningxia, Guangdong	Water surface, desert, grassland	4%-33%

Recommendation Preface

Martin Green

Scientia Professor at the University of New South Wales, Sydney and Director of the Australian Centre for Advanced Photovoltaics

Solar cells with both polarity contacts on the back, now almost universally known as interdigitated back contact (IBC) cells, have a much longer history than any of the other contending silicon (Si) technologies. White and Schwartz [I] are credited with first suggesting the IBC approach for Ge p-i-n diodes in 1964 for use in thermophotovoltaics. Lambert and Schwartz [II] reported the first Si IBC cells in 1975, demonstrating a creditable 15% conversion efficiency under concentrated sunlight. Dick Swanson's Stanford team showed the full potential of the IBC approach in the 1980s with a "point contact" cell design that restricted doped regions in the cell, setting new records for efficiency under concentrated sunlight with up to 27.5% reported [III]. Interest steadily shifted to use under non-concentrated sunlight, with a new one-sun record of 22% efficiency set in 1988, the first Si cell above 22%. Although PERC was first above 23%, 24% and 25% [IV], IBC now with heterojunction (HJT) contacts (HBC), resurfaced post-2014, first above 26% in 2016 and 27% in 2023, with some form of IBC likely the first above 28% in the near future, eventually above 28.5% and perhaps even 29%.

Apart from high efficiency, having both polarity contacts on the rear allows other features that contribute to improved field performance from IBC technology. One is a controlled reverse breakdown voltage that limits the power dissipation in the cell if it becomes reverse biassed, preventing thermal failure of the cell or of its surrounding encapsulation. Also the direct back-to-back interconnection of IBC cells increases reliability since avoiding issues with the traditional front-to-back interconnectors.

High efficiency, however, is the feature that I believe will make IBC the dominant photovoltaic technology within the next 5 years. IBC has a clear efficiency advantage over TOPCon in short-circuit current (Isc), by avoiding top surface contact shading, in open-circuit voltage (Voc) by replacing the B-diffused top contact by either a HJT or TOPCon p-type passivated contact, and in fill factor (FF) by this higher voltage giving the ability to access Auger-enhanced values [V]. The advantage over HJT is limited to higher Isc, not only by avoiding metal shading loss but also losses due to HJT's additional absorbing top surface layers.

Over the last decade, the industry has made two challenging transitions from a well-established technology to a more difficult but higher performance technology, from Al-BSF to PERC then from PERC to TOPCon. With the transition to tandem cells indefinitely deferred due to inadequate perovskite stability, the next such transition is likely to be from TOPCon to IBC, in either HBC or hybrid HTBC implementations.

Back Contact (Bc) Solar Technology Development White Paper | **Recommendation Preface**

Dr. Christos Monokroussos

Global Segment Coordinator for Solar of TÜV Rheinland Group

In the relentless pursuit to harness the sun's power, the photovoltaic industry has continually sought ways to enhance the efficiency of solar cells. Intent on expanding the limits of what is achievable, innovative designs such as back contact (BC) solar cells have emerged as significant advancements in technology and functionality. By positioning all electrical contacts on the rear side, these cells feature an unobstructed light-absorbing surface, eliminating the shading losses associated with front-side, thus raising the bar for energy conversion efficiency.

The strength of the BC configuration lies in its universality, as it harmonizes seamlessly with an array of cutting-edge solar technologies. By integrating with various technologies—such as TOPCon's enhanced passivation capabilities and HJT's low-temperature processing advantages, there combined advancements signal the dawn of a new era for photovoltaic efficiency. PV modules with BC solar cells are not only pivotal in advancing the frontier of photovoltaic efficiency, but they also showcase significant benefits across essential performance indicators. These include enhanced conversion efficiency, minimized Light Induced Degradation (LID), as well as improved resistance to shading and hot-spot effects.

To unlock the full potential of these technological synergies, it is crucial to adhere to a rigorous standard of testing, one that mirrors the strenuous conditions encountered during actual operation. TÜV Rheinland excels in this domain, with its commitment to technical accuracy taking center stage. To accurately determine the Standard Test Conditions (STC) power rating of a solar cell, advanced testing methodologies such as light soaking—critical for stabilization— are employed. This process is complemented by spectral mismatch correction, which adjusts for discrepancies between the emission spectrum of the solar simulator and the standard solar reference spectrum, thereby guaranteeing that the measured electrical output represents close to real solar conditions. Dynamic IV measurement can further enhance the precision of these evaluations by charting the instantaneous relationship between current and voltage while concurrently mitigating the impact of capacitive effects that can mask the genuine electrical performance of the solar cells. The acquisition of the steady-state IV curve, free of transient disturbances, provides stakeholders with a robust basis for gauging long-term performance and energy yield.

Through state-of-the-art testing protocols, TÜV Rheinland upholds its commitment to precision and reliability. The organization's specialists bring an unmatched level of accuracy to photovoltaic technology evaluation, contributing profound insights that drive innovation and assuring manufacturers and consumers of the integrity of their investments in solar energy.

In this background the evaluation and certification process by TÜV Rheinland brings confidence to stakeholders who can navigate in the complex landscape of photovoltaic technology, reassured by the thorough adherence to stringent standards that facilitate the shift towards a sustainable and renewable energy future.

Chu Junhao

Academician of Chinese Academy of Sciences and Professor of Fudan University

In the context of accelerated transition of the global energy mix, PV technology, as the core driving force for realizing the dual carbon goals, is experiencing revolutionary technological iteration and industrial upgrading. Back Contact (BC) cell technology, with its unique structural advantages and significant efficiency potential, has become an important breakthrough in leading the PV industry to a higher level.

In the development history of PV technology, every technological innovation is accompanied by the challenge of improving the level of photoelectric conversion efficiency. BC technology eliminates frontside busbar shading by placing the electrodes on the backside of the cell, an ingenious construction that allows the cell to maximize sunlight absorption and naturally boosts crystalline silicon solar cell efficiency. In more than 40 years since 1975 when this idea was conceived by the American scientists, many attempts have been made, but this technology has failed to achieve large-scale industrialization due to its complex process and high cost.

In recent years, through the unremitting research of Aiko, LONGi and other enterprises, BC technology has finally realized low-cost, high-yield large-scale production in the hands of Chinese enterprises, so that this highly creative technology can be made available to common PV users. This achievement not only highlights the innovative strength of Chinese PV enterprises, but also confirms the feasibility of large-scale application of BC technology.

In the future, continued breakthroughs in PV technology are necessary to achieve the dual carbon goals. On the supply side, synergies with new power grids, new energy storage system, PV hydrogen production and other segments must be considered. On the demand side, brand-new application scenarios must be explored in buildings, transportation, communications and so on. To reach these goals, the PV industry must evolve from the "unbridled growth" stage towards refined and standardized development, in order to play a role in wider applications.

BC technology evolved from "no man's land" in terms of materials, process, equipment, and other aspects. The standardization of BC technology is not only an urgent need for the development of BC technology itself, but also an issue that must be faced by BC as the "new quality productive forces" leading the PV industry to achieve high-quality development, and also the tool that allows China's PV industry to access the global market and secure its technological discourse power.

It is expected that the release of this White Paper will help colleagues in PV industry who are interested in embracing advanced technologies to clarify the technological pulse, gather consensus on innovation, and jointly write a new chapter for the high-quality development of the PV industry.

Shen Wenzhong

Director of Solar Energy Research Institute, Shanghai Jiao Tong University, and Professor of Shanghai Jiao Tong University

In the context of accelerating the global energy transition, solar energy, as a clean, renewable and high-quality energy source, is becoming more and more important in the energy mix. The continuous innovation of solar cell technology is not only the core driving force to promote the progress of the PV industry, but also an important support to realize the green transition of energy. Back contact (BC) solar cell technology has reshaped the technological landscape of PV cells with its unique advantages, leading the industry to a new stage of development. Against this background, the PV BC Technology Industry White Paper is extremely valuable and deserves to be read in depth by everyone concerned with the PV industry.

The White Paper is far-sighted and insightful into industry trends, starting from the current development trends and challenges of the global PV industry, intensively analyzing the technical principles, structural innovations and core performance advantages of BC cells, comprehensively describing the application value of BC modules, the standard system and authoritative certification, and systematically depicting the construction of the BC ecosystem, the building of the access system and the outlook for development. Through the analysis of industry data and actual cases, it points out the way forward for the industry peers and helps them to make the right strategy and seize the market opportunities.

Although BC technology has immense potential, it faces many challenges in the early stage of development. The White Paper analyzes the problems and explores the coping strategies at the same time, deeply analyzes the complexity of the preparation process, cost control and yield enhancement, etc., and systematically introduces the active practice of enterprises in the industry to explore the path of cost reduction and efficiency enhancement through collaborative innovation and process optimization, which provides a reference idea for other enterprises, and helps the whole industry break through the development bottleneck of BC technology together.

Therefore, whether you are a practitioner who has been deeply involved in the PV field for many years, an investor who is concerned about the new energy track, or a policymaker who is committed to promoting the energy transition, you will be able to obtain valuable information from this White Paper, which is hereby recommended.

Shen Hui

Director of Yangtze Institute for Solar Technology

In terms of conversion efficiency, long-term stability, environmental friendliness and economic efficiency, there is no doubt that crystalline silicon solar cells will be the dominant products that will continue to lead the development of PV technology. The conception and industrialization of BC technology came from the United States, but due to its complexity and high cost, this technology has not seen much development. Thanks to the technological innovation of the enterprises represented by Aiko and LONGi, this technology has come to the stage of large-scale industrialization, and has been widely applied at home and abroad. It has been highly recognized by the market, and has produced good application results.

With the publishing of this White Paper, we hope that BC enterprises will continue to increase R&D investment, accelerate the construction and improvement of the BC silicon solar cell industrial ecology, and further improve the conversion efficiency and reduce the production cost, so that this product can be more popularized and applied.

The joint development of BC by two leading companies is a new phenomenon in the PV industry, and the joint release of the White Paper is definitely worth celebrating. For this reason, I would like to share two poems as a token of appreciation of the two enterprises:

With hard work and innovative spirit, we look forward to a brighter future. With scientific and imaginative mind, we stride toward a greater ambition.

Great aspiration defines our day, strong business defines our gain. Green energy refines our society, green technology revitalizes our country.

Back Contact (Bc) Solar Technology Development White Paper | **Recommendation Preface**

Wu Jinhua

Executive Chairman of Solar Power Branch of China Electricity Council (CEC)

Against the background of accelerated transition of global energy mix, PV technology, as a core pillar of renewable energy, is ushering in a new wave of technological revolution. As an important force in promoting the high-quality development of the power industry, the Solar Power Branch of China Electricity Council is highly concerned about and supports the innovation and breakthroughs in PV technology. With the release of the White Paper on Industrial Development of Back Contact (BC) Cell Technology, we sincerely recommend this technical guide that gathers the wisdom of the industry, with a view to providing scientific references for industry decision makers, practitioners and researchers, and jointly promoting the PV industry to move towards a higher-efficiency and more sustainable future.

I.Technological innovation leads industrial change

Back contact (BC) technology, with its unique structural design, has become a critical path to break the efficiency bottleneck in the PV field. By placing all the electrodes on the backside of the cell, it significantly reduces optical losses and realizes higher photoelectric conversion efficiency. It can save land and construction costs in complex scenarios such as desert and barren land, and enhance the power generation revenue with the same production area, fully demonstrating the dual advantages of BC technology in terms of performance and reliability.

II.Diversification of application scenarios and empowerment of new power systems

The compatibility and scenario adaptation of BC technology are particularly impressive. As a platform technology, it can be integrated with TOPCon, HJT and other technical routes to continuously unlock efficiency potential. At the same time, facing the challenge of a high proportion of new energy being diverted to the grid, the high efficiency and stability of BC technology provides strong support for the safe operation of the new power system.

III.Looking to the future, drawing a blueprint for green energy

China's PV industry has gone through technology iterations such as mono-crystalline cell and PERC, and has always driven the global energy change with innovation. As the "crown jewel of crystalline silicon", BC technology represents the mainstream direction of PV efficiency breakthroughs in the future. Taking the White Paper as a guide, let's join forces, deepen technological research and development, expand application scenarios, optimize industry chain collaboration, and jointly convert BC technology from "laboratory potential" into "scale value", and inject powerful energy into a new type of power system with new energy as the main body to help China achieve the dual carbon goals with high quality.

Solar Power Branch of China Electricity Council will continue to play its role as a platform, push the whole industry to a consensus, and promote technology standardization and industrialization. With an open and innovative attitude, we will welcome the new era of PV technology and contribute Chinese wisdom and Chinese solutions to the green and low-carbon development!

Zhang Xiaozhao

Director of the New Energy Operations & Maintenance Committee of China Electric Equipment Management Association

Former Deputy Director of New Energy Business Unit of China Huaneng Group Co., Ltd.

The wave of energy revolution rushes forward. Over recent 20 years, China's PV industry has been unrelenting and at the forefront of the global wave of technological innovation. From PER C technology breaking through the bottleneck of mass production efficiency, to TOPcon opening a new era of bifacial passivation, to HJT reshaping the technology paradigm with ultra-thin heterojunction, each technological leap has elevated the theoretical limit of photoelectric conversion. Today, when the industry is once again at the crossroads of technological iteration, BC (back contact) technology, with its revolutionary structural innovation, is becoming the key to opening a new chapter in the PV industry.

Compared to traditional cell structures, BC technology maximizes the light absorption area by shifting all the electrode busbars to the backside of the cell, completely eliminating frontside metal shading losses. This disruptive design not only brings significant improvement in conversion efficiency, but also achieves better reliability through structural cylinderization.

The evolution of PV technology is by no means an isolated event. The maturity of BC technology has benefited from breakthroughs in China's entire industrial chain, including material systems, precision manufacturing, and encapsulation processes. The collaborative innovation of nanoscale amorphous silicon passivation layer, atomic layer deposition metallization process, and high-precision laser transfer printing technology has made the precise manufacturing of back contact structures possible. This means that the PV industry has made the leap from a single technological breakthrough to systematic engineering capability, and also indicates that the technology competition will enter a new stage of "system engineering innovation".

As global PV leaders, LONGi and Aiko have jointly compiled this White Paper, which is not only a systematic review of the past technologies, but also a forward-looking strategic starting point for the future of the industry. By analyzing in detail the core process route, key equipment selection and mass production quality control system of BC technology, and at the same time establishing a full life cycle assessment model, we provide the industry with a technical roadmap from laboratory to industrialization.

By now, carbon neutrality has become a global consensus. Under China's general energy security strategy of "four revolutions and one cooperation" proposed by General Secretary Xi Jinping, on our way to complete, accurate and comprehensive implementation of the new development philosophy and establishment of a new development pattern, PV technological innovation carries the important mission of energy transition of humankind. BC technology, with its high efficiency, high reliability and high adaptability, is opening up the market trading and price mechanism for PV to adapt to the development reality, and promoting PV's fair participation in the market trading after the new value dimensions of the system balance from the pure pursuit of cost reduction to the "optimal levelized cost of energy", and upgrading from an energy substitution tool to a core unit of a new type of power system. We hope that the White Paper, which is a product of industrial wisdom, will inject innovative kinetic energy into the global PV industry, and help us open a new world of green energy.

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Back Contact (Bc) Solar Technology Development White Paper | **Recommendation Preface**

Li Zhenguo

President and Founder of LONGi

The release of the White Paper on the Development of Back Contact (BC) Cell Technology has systematically analyzed the development direction of the industrialization of this technology, and provided new ideas for the technological iteration of China's PV industry through collaborative innovation in the industry chain. LONGi works with partners from upstream and downstream sectors of the industrial chain to solve three key issues in the field of PV through the trinity innovation system of "R&D-standards-application": to enhance the efficiency of industrialized application of laboratory results, to strengthen the technical synergy of each link of the industrial chain, and to promote the in-depth combination of technological innovation and the needs of end-users. This cross-sectoral cooperation model provides a practical reference to promote the industry's high-quality development.

The industrialization of BC technology is not a solo dance of a certain enterprise. When a technology can gather the greatest consensus of the industrial chain, it will be escalated from an enterprise strategy to the mainstream of the industry. As a global leader and core driving force of PV technology, China's ecological development of BC technology is once again providing both inclusive and sustainable solutions for the global energy transition. From open source innovation to open innovation, it marks the strategic upgrade of China's PV industry from a "manufacturing leader" to a "technological rule definer". In this industrial change consisting of efficiency revolution and value upgrading, the Chinese PV enterprises take technological innovation as the fulcrum to pry the deep reconstruction of the global energy ecosystem.

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Chapter 1
Introduction

1.1 Trends and challenges of global PV industry [1]

As the global energy structure rapidly shifts toward low-carbon and sustainable solutions, photovoltaics (PV) has emerged as a critical pillar of renewable energy, transforming the energy landscape at an unprecedented pace. By 2030, according to the International Energy Agency (IEA) forecast, the additional global installed capacity based on renewable energy will exceed 5,500 GW, of which PV will account for more than 70%, surpassing wind energy to become the largest renewable energy source.

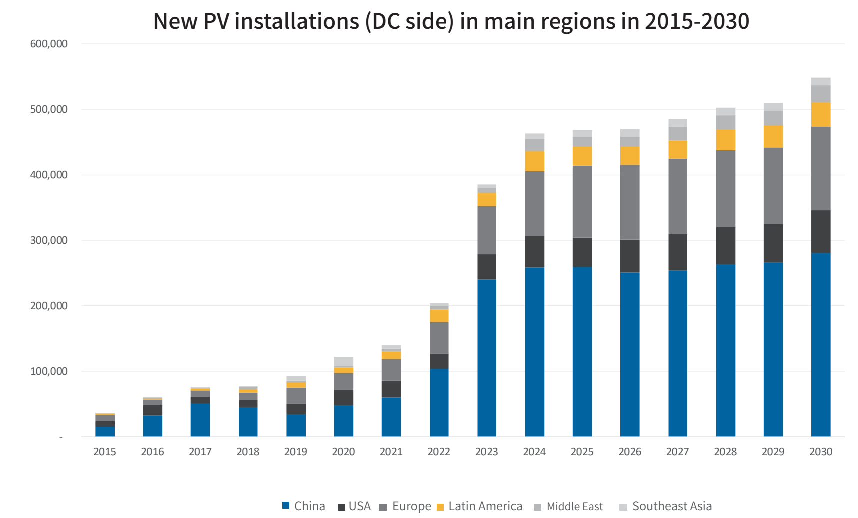
It is estimated that by 2050, the global cumulative PV installations will reach 18,200 GW, accounting for about 50% of PV electricity generation. It marks that PV electricity generation has jumped from "supplementary energy" to "main energy" of the global power system. However, at the same time of rapid growth, the industry also faces systematic challenges such as excess capacity, trade barrier, price pressure and iteration of technical routes.

1.1.1 Market size continues to expand, emerging market shows great potential

In recent years, the PV industry has entered a new stage of large-scale expansion. According to the prediction of the International Renewable Energy Agency (IRENA) and industry research institutions, the global PV installed capacity will exceed 580 GW in 2025, an increase of nearly 150% compared with 2022, and the market scale will expand at a compound growth rate of more than 20% for three consecutive years. This growth pattern is the result of the so-called "two-wheel drive": the core markets continue to be on the leading edge because of their policies and technological advantages, while emerging markets rely on resource endowments and energy demand gaps to rise rapidly, and the global PV industry presents a new trend.

The three core markets including China, Europe and the United States are expected to contribute more than 70% increment in 2025. China is driven by both "large-scale wind and PV base" and DG PV. In 2024, the installed capacity increased by 277.57 GW, and the accumulated installed capacity exceeded 880 GW. It is estimated that the new installed capacity will be 255 GW in 2025, accounting for more than 50% of the new PV installations in the world; Europe, bolstered by energy security initiatives and increased funding, may reach 75 GW of new installations in 2025. The U.S. market, stimulated by the Inflation Reduction Act, added 50 GW in 2024 while accelerating domestic manufacturing. However, due to economic fluctuations, the new PV installed capacity will fall back to 45 GW in 2025.

At the same time, emerging markets are rising significantly, reshaping the global PV geo-pattern. The Middle East region releases its potential through policy guarantee. Saudi Arabia and United Arab Emirates have set the target that 50% of energy consumption will be renewable energy from 2030 to 2050. In 2024, PV installations increased by 17.8 GW, with a year-on-year growth of 130%, and it is expected to increase by more than 97 GW in the next five years. Southeast Asia is guided by carbon neutrality commitment, with 62 GW of new installed capacity accumulated from 2024 to 2030, accounting for 56% of utility projects; Philippines and Indonesia mainly focus on utility, while Vietnam and Thailand focus on DG; Latin America accelerates its development by virtue of light resources and policy incentives, Brazil and Chile attract investment through green bonds and tax reduction policies, and the new installed capacity will reach 30 GW in 2025, with a year-on-year growth of 24%. Through quantitative targets, fiscal incentives, foreign investment access and technological innovation, countries have built a multi-level energy transition framework to further push forward the diversification and regionalization of the global PV market.



Data source: S&P Global Southeast Asia installed capacity is the sum of the 7 countries including Malaysia, the Philippines, Singapore, Thailand, Myanmar, Vietnam and Indonesia

1.1.2 PV industry chain: China's dominant position is further strengthened and technology iteration accelerates

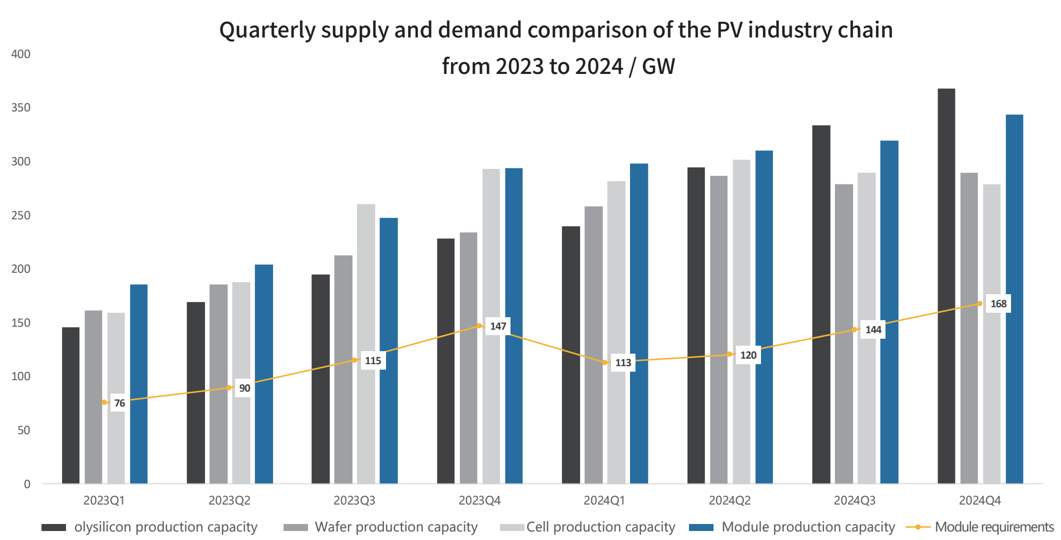
The silicon-based PV manufacturing industry chain mainly includes four links, i.e. polysilicon, wafer, cell and module. After decades of development, China's PV industry chain has realized leapfrog development from technology import to independent innovation, from imitation to global leadership. By the end of 2024, China's production capacity for polysilicon material, wafers, cells, and modules had reached 95%, 96%, 90%, and 82%[2] of the global total, respectively, establishing an absolute advantage in global manufacturing.

In recent years, China's enterprises have been at the forefront of advanced PV cell technology. Following November 2022, LONGi set the highest global record for silicon solar cell conversion efficiency. By the end of 2024, the conversion efficiency records of the main cell technologies including TOPCon, HJT, BC and perovskite crystalline silicon stack technologies were set and maintained by China's enterprises. China's PV technology has evolved from technology import to independent innovation and from large-scale expansion to high-quality development, now firmly ranking first globally and accelerating the technological iteration of the global PV industry.

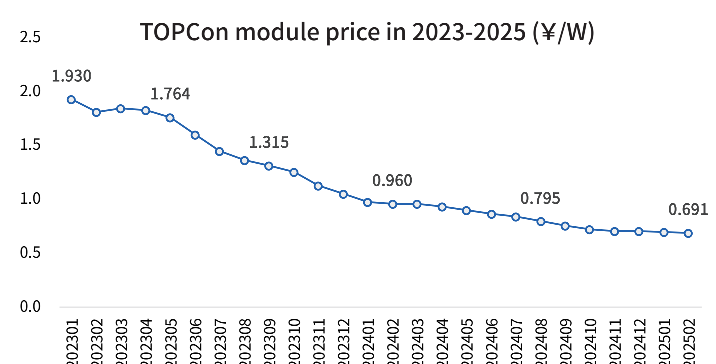
By the end of 2024, the market share of N-type modules exceeded 80%[3]. Behind the rapid growth of market share of N-type module is its significant advantages in conversion efficiency, power generation capacity, reliability and cost. In 2024, the mass production efficiency of TOPCon and HJT reached 25.4% and 25.6% respectively, and the BC mass production efficiency exceeded 27%, which was much higher than the mass production efficiency of PERC cell, which was about 23.8%; on the other hand, with the popularization of technologies such as scale effect and zero busbar (0BB), the cost of N-type cell gradually decreased.

1.1.3 Staged excess capacity and intensified price competition in the industry

Due to the continuous and rapid expansion of production capacity, the production capacity of the four links of the PV main industry chain was greater than the terminal demand from 2023 to 2024. According to S&P Global statistics, the new PV installed capacity (DC) in the world in 2024 was about 545 GW, but the production capacity of polysilicon materials, wafers, cells and modules was above 1,000 GW. The PV market encountered a temporary mismatch between supply and demand, resulting in intensified market competition and downward product prices.



In the context of PV market oversupply, some enterprises took the low-price competition strategy, the industry fell into "rat-race" vicious competition, and module prices exhibited long-term decline. At the beginning of 2023, the module price was ¥1.93/W. After two years of continuous decline, it dropped to ¥0.691/W by February 2025, a decrease of 64%.



The sharp drop in module prices has severely compressed the profit margins of PV companies, and some companies that lack competitiveness have been eliminated. The low-price competition will inevitably cause the industry to fall into a vicious circle, affecting product quality and destroying industry innovation. Only by insisting on cost reduction and efficiency improvement, developing technologies and products with higher conversion efficiency and eliminating outdated capacity, can we break the deadlock and push the industry back to high-quality development.

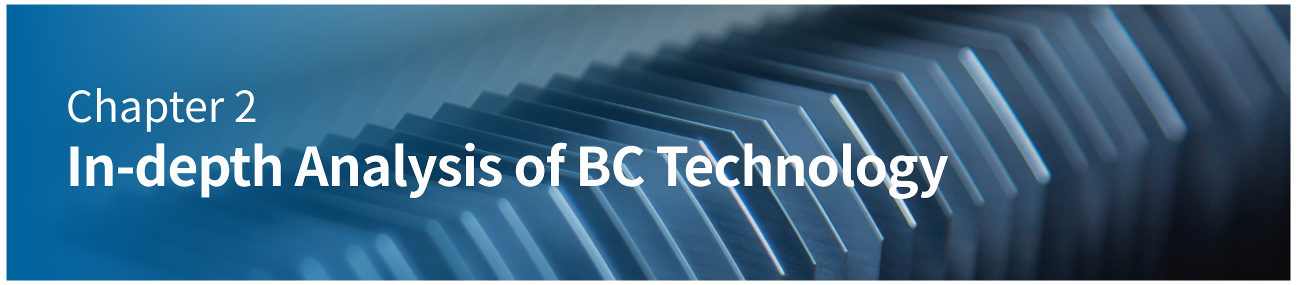
1.2 Industrial background of BC technology iteration

As the development history of the PV industry has proven, when the conversion efficiency of a new generation cell enabled by a new technical route is significantly higher than that of the previous generation, it will quickly replace the former and become the mainstream product in the market. As of 2017, Al-BSF(aluminum back surface field) cell had been the mainstream product in the market, with an average mass production efficiency of about 19%. However, the average mass production efficiency of PERC cells reached 21% in 2017, which was 2% higher than Al-BSF cells, so it quickly replaced Al-BSF cell as mainstream product in 2018. By 2023, the average mass production efficiency of PERC cell was about 23.5%, while the average mass production efficiency of TOPCon cell was about 25%. Although the cost competitiveness of TOPCon cell relative to PERC cell has not yet appeared at this time, the market penetration will be accelerated by virtue of the efficiency advantage of 1.6 percentage points. In 2024, the market share nearly reached 80%, completing the technical iteration of PERC.

At present, under the background of increased sensitivity of owners to LCOE, mismatch between supply and demand of TOPCon capacity, and homogeneous low-price competition between the products, the demand for the next generation of products with high conversion efficiency was increasingly high. In the field of single-junction silicon cell technology, BC technology has maintained an absolute lead in both laboratory and mass production conversion efficiency after nearly 8 years of continuous R&D investment. Over the past two years, BC has repeatedly set new world records for the efficiency of single-junction crystalline silicon cells, with the latest record reaching 27.81%. Meanwhile, the efficiency of mass-produced BC cells is approximately 1.6% higher than that of TOPCon cells. This efficiency gap is similar to that of the previous two rounds of technological iteration and shows a trend of further expansion. Clearly, BC has become the pinnacle of single-junction silicon cell technology.

Therefore, it is reasonable to assume that BC cells, as the ultimate technology for single-junction silicon solar cells, have reached a state of maturity and are destined to guide the healthy development of future battery technology innovation and the industry.

The emergence of BC cell is by no means accidental. It is driven by continuous pursuit of efficiency limit by PV industry, the accurate response to the scenario demand in DG market, and the technological competition in the background of global energy transition. Thanks to SunPower's laboratory breakthroughs and the industrialization efforts of companies like Aiko and LONGi, BC technology is evolving from a "niche high-end" technology to "mainstream popular" technology.



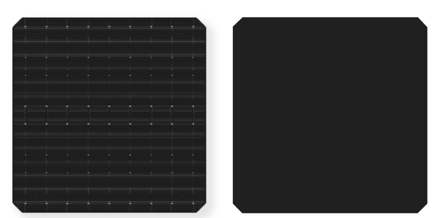
Chapter 2
In-depth Analysis of BC Technology

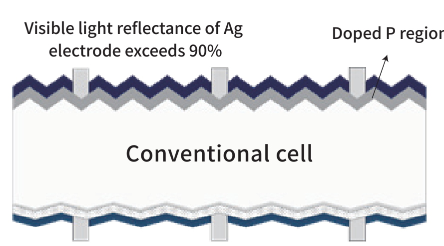
2.1 Technical principle and structural innovation

2.1.1 Introduction to BC cell technology - revolutionary structural design breaks the optical bottleneck

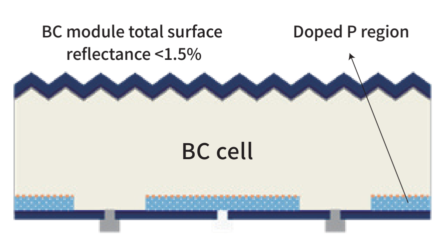
BC cell (Back Contact Cell) technology integrates all positive and negative electrodes of the cell on the backside through the **full-backside cross electrode technology**, completely eliminating the busbar shading on the frontside of the traditional cell, maximizing the light absorption area, realizing the paradigm shift of PV cell design, comprehensively improving the conversion efficiency of PV cells from the optical and electrical aspects, and breaking through the efficiency limit of crystalline silicon solar cells, and is regarded as the ultimate form of single-junction silicon solar cells. Its core features and advantages are as follows:

a. Zero shading optical surface:
By eliminating the 3-5% front-side metal gridline shading inherent to conventional solar cells, this innovation enables more photons to reach the silicon absorber layer. The resulting incident photon utilization rate increases to 97.3%, generating higher short-circuit current density (Jsc) and ultimately improving overall power conversion efficiency.

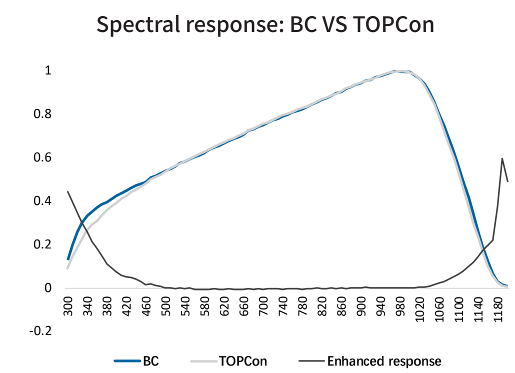


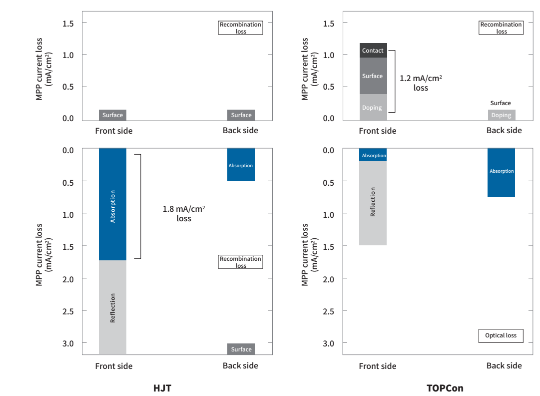


b. Non-doped layer parasitic absorption
The PN junction of the BC cell is located on the rear side of the cell, with no p-n junction on the front side. This eliminates the parasitic absorption caused by the diffused junction from front-side doping, thereby enhancing the absorption and utilization of photons. Without the need for front-side carrier collection, greater flexibility is achieved in optical and passivation design, enabling optimized light trapping and surface passivation to further improve power conversion efficiency.



c. Bifacial passivation enhancement:
Al_2O_3/SiN_x full-area stacking passivation realizes the surface recombination velocity <10 cm/s, improves the spectral response of the cell as a whole, especially the short-band response by more than 10%, and the carrier lifetime exceeds 5ms (conventional: ~3 ms).

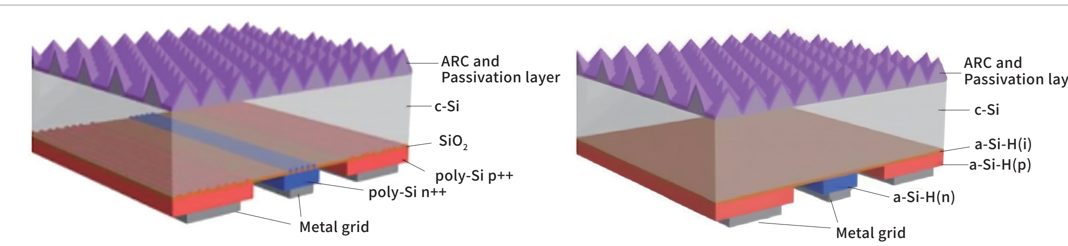




d. Platform technology expandability:
BC technology is essentially a structured electrode platform technology, which can create a composite efficiency improvement solution together with the mainstream cell technologies. At present, BC technology with TBC as the main structure has been fully mass-produced, and other BC technologies are also advancing toward mass production.

Progress of integrating BC with different technical routes

Technology convergence route	Laboratory cell efficiency	Efficiency of mass-produced module	Industrialization progress
HJT amorphous silicon layer +BC back contact	27.81%	/	Pilot line
TOPCon polysilicon passivation +BC metallization	⩾27.1%	24.4%	2025＞100 GW



TBC HBC

TBC cell technology combines IBC's high short-circuit current (Isc) with TOPCon's excellent passivation contact characteristics for higher efficiency.
Key Advancement: TOPCon cell passivation technology is used to improve passivation effect and open-circuit voltage (Voc), with basically no current loss.
HBC cell technology combines the busbar-free frontside design of IBC with the superior surface passivation performance of HJT amorphous silicon, possesses the dual advantages of high Isc and high Voc, and represents the maximum efficiency level of single-junction cells.
Key Advancement: hydrogenated amorphous silicon (a-Si:H) is used as a bifacial passivation layer to form a local heterojunction structure on the backside to obtain a high Voc.

2.1.2 Evolution of theoretical limit of crystalline silicon solar cell

2.1.2.1 Six decades of breakthrough in fundamental theory

The iteration of the crystalline silicon theoretical model is the cornerstone of industrial progress: from the Shockley-Queisser universal model in 1961 to the Brendel model in 2018, the academic community has continuously corrected the boundary of the limit efficiency of crystalline silicon solar cells.

Comparison of theoretical model milestones for crystalline silicon solar cells

Model	Core breakthrough	Efficiency correction mechanism	Impact on industry
S-Q Model	Established delicate balanced theoretical framework	The theoretical limit of 33.7% proposed	Laying the foundation for PV material selection (1960s-1980s)
Kerr Model	Quantified Auger compound enhancement effect	Efficiency correction-4.65%	Promoting the development of low doped wafer technology
Richter Model	Solar spectroscopy and silicon optical parameter corrections	Efficiency rebound of +0.38% to determine the theoretical limit of 29.43%[4]	Directed the development of bifacial cell/stack technology (2013-now)
Brendel Model	Accurate Lambertian light trapping calculation + photon cycle compensation	Efficiency increased by +0.13%, theoretical limit of 29.56% established[5]	

2.1.2.2 Technical intergenerational difference of theoretical efficiency ceiling

In 2018, Schimit et al. obtained the theoretical limit efficiency of PERC, HJT and TOPCon through selection and comparison. Subsequently, in 2021, LONGi Green Energy Technology Co., Ltd. used microcrystalline silicon to replace amorphous silicon, which increased the theoretical limit efficiency of HJT to 28.5%. In 2022, Peibst et al. integrated and optimized BC cell and TOPCon technologies based on Brendel model deduction, and simulated BC cell limit efficiency up to 29.1%[6], approaching silicon-based limit.

Benchmarking of theoretical limits of technical routes

Technical route	Theoretical efficiency	Difference from silicon-based limit	Core bottleneck
PERC	25.0%	4.4%	Back surface recombination($J_{\circ}$ >200 fA/cm²)
TOPCon	28.7%	0.7%	Carrier transport and optics cannot be balanced
HJT	28.5%	0.9%	Large optical loss
BC	**29.1%**	**0.3%**	Realization of high precision patterned electrode

Dimension	Physical limits of crystalline silicon		Technical limits of BC
Theoretical basis	Richter Model(2013)	Brendel Model(2018)	MarcoPOLO Model (2022)
Core parameters	W=110μm wafer thickness	W=98.1μm wafer thickness	Photonic crystal + POLO passivation
Efficiency value	29.43%	29.56%	29.1%
Key limiting factor	Auger compound dominance		Interface state density(>1e10 cm^{-2})

With the continuous investment of PV manufacturing enterprises in technology research and development, Chineseenterprises have continuously rewritten the laboratory efficiency records of various technical routes in recent 3 years, and the laboratory cell efficiency has been approaching the theoretical efficiency limit. Meanwhile, the mass production efficiency of each technical route has also been rising rapidly.

Special note: In March 2025, BC cell efficiency was certified by ISFH to have broken the world record again, reaching 27.81%, with only 1.3% efficiency gap compared with the theoretical process efficiency limit, which signifies that BC is the technology closest to the theoretical limit.

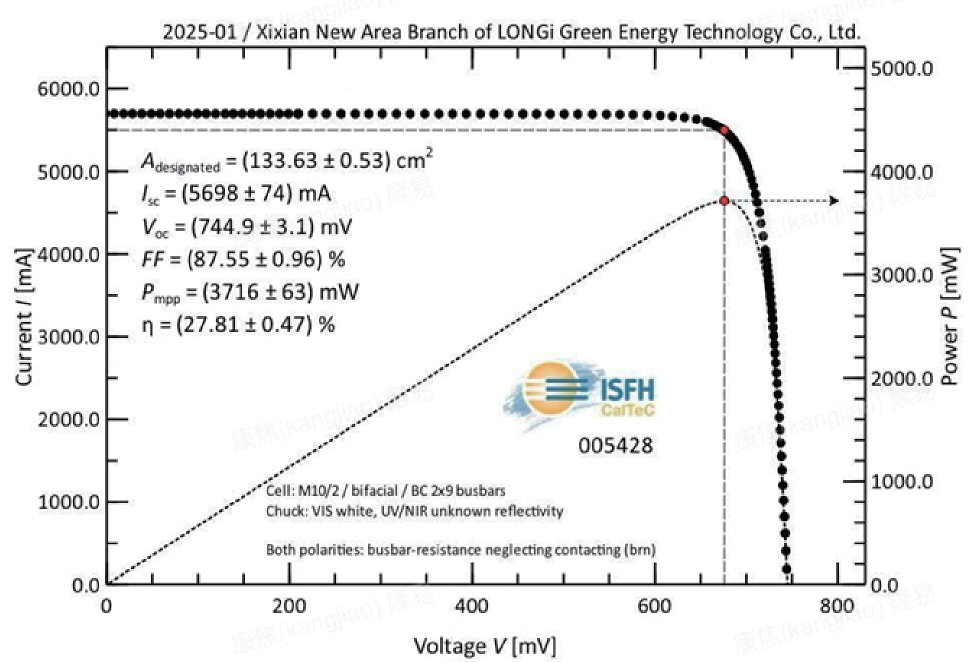


Fig. 2: Plot of the measured current-voltage characteristics under standard test conditions.

2.1.3 Analysis of intergenerational revolution of PV technology

2.1.3.1 Cell technology comparison and analysis

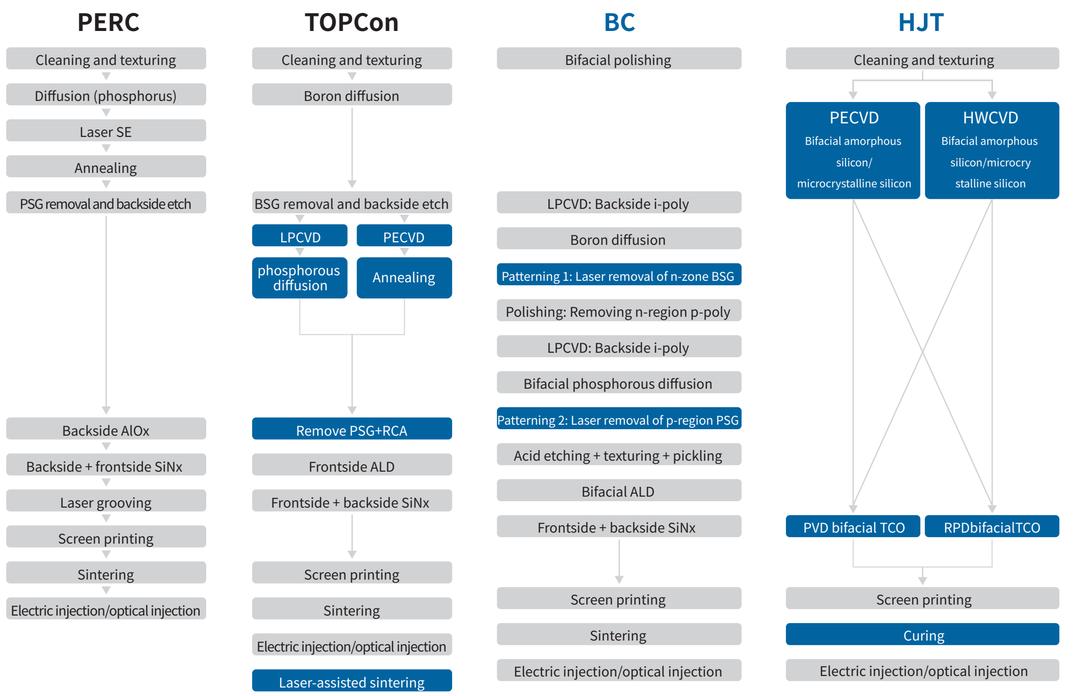
The first generation technology in the history of PV technology development was Al-BSF cell, which dominated the mainstream market before 2017. However, the backside of this cell was fitted with aluminum electrodes, which are directly in contact with silicon, leading to serious metal contact recombination, limiting efficiency. Therefore, the researchers used the rear surface passivation method and passivated the back surface with Al_2O_3/SiN_x, which effectively suppressed the metal contact recombination, but the Al electrode in local contact still caused a large recombination loss, so the upper limit of PERC cell efficiency was also low.

Subsequently, in 2013, Fraunhofer Institute of Germany proposed a new passivation structure, which used this passivation contact structure of tunnel silicon oxide + doped polysilicon to achieve efficient carrier selection and reduce contact recombination loss. This was how TOPCon cell was developed. However, there are still serious recombination loss and parasitic absorption loss on the frontside of TOPCon cells, so P and N dual-region passivation contact structures were developed, and at the same time, high efficiency BC cells were developed to minimize the parasitic absorption on the frontside of the cell. It can be seen that passivation technology has promoted the development of cell technology, and the ultimate goal of development is to achieve higher conversion efficiency and lower levelized cost of energy.

From PERC to BC, the nature of PV cell technology iteration is a spiral upgrade of "optical management" and "electrical optimization". PERC, with its low cost, lays the industrial foundation, TOPCon improves on the technology through compatibility, HJT redefines the efficiency limit with heterojunction, and BC technology realizes the leap-forward development of technology through structural revolution and ultimate efficiency.

Overall comparison of PV cell technology

Technical dimension	PERC	TOPCon	HJT	BC
Physical structure	Frontside:n+emitter + silver busbar Backside:Al_2O_3/SiN_x	Frontside: Boron-diffused emitter Backside: SiO_x tunnel layer+n+ polysilicon layer	Bifacial: a-Si heterojunction +TCO layer symmetrical structural design	Frontside: zero busbar and fully passivated Backside: interdigitated electrodes
Efficiency enhancement mechanism	- Voc↑15-20mV - bifaciality 65-75%	- Contact recombination velocity<100 cm/s - bifaciality 75-80%	- Carrier lifetime>5ms - bifaciality~90%	- Light utilization rate↑3-5% - Recombination loss↓60%
Key process parameters	- Texturing reflectance <11% - Laser opening 20-30 μm	- Tunnel layer 1-2 nm - Polysilicon layer 20-150 nm	- TCOthickness 70-100nm - Process temperature<200°C	- Electrode spacing50-100μm - Laser accuracy±2μm



Cell process flow comparison diagram[7]

Six-dimensional capability assessment of four-generation technology

Evaluation dimensions	PERC	TOPCon	HJT	BC
Efficiency potential	★★	★★★☆	★★★★	★★★★★
Process compatibility	★★★★★	★★★★	★★	★★★★
Bifacial gain	★★★	★★★★	★★★★☆	★★★★
Temperature coefficient	-0.35%/°C	-0.29%/°C	-0.24%/°C	-0.26%/°C
BOS cost advantage*	-	-2.3%	-2.8%	-7.8%
Technology maturity	Withdrawal from the market	Mass production	Mass production	Mass production

*Balance of System (BOS) costs encompass all PV system expenses excluding solar modules, mainly includes: racks, inverters, cables, step-up substations , etc.

2.1.4 Cost Analysis

In recent years, benefits from the rapid promotion of BC mass production, the initial scale effect has become evident. The cost investments in equipment, materials, etc., have rapidly narrowed the gap with TOPCon. As the manufacturing yield rate of mainstream enterprises has increased to over 98% and the efficiency has exceeded 27%, the difference in manufacturing costs between BC and TOPCon is currently controlled within ¥0.05/W. In the future, BC technology can still achieve rapid cost reduction through the following three aspects. It is expected that the mass production cost of BC will be comparable to or even lower than that of TOPCon within the next year.

① Improvement in battery conversion efficiency: The current mass production efficiency of BC cell has exceeded 27%, and the subsequent mass production efficiency of batteries will continue to increase.

② Scale effect: With the large-scale deployment of BC production capacity, it is expected that the production cost of BC will further decline as the mass production scale expands.

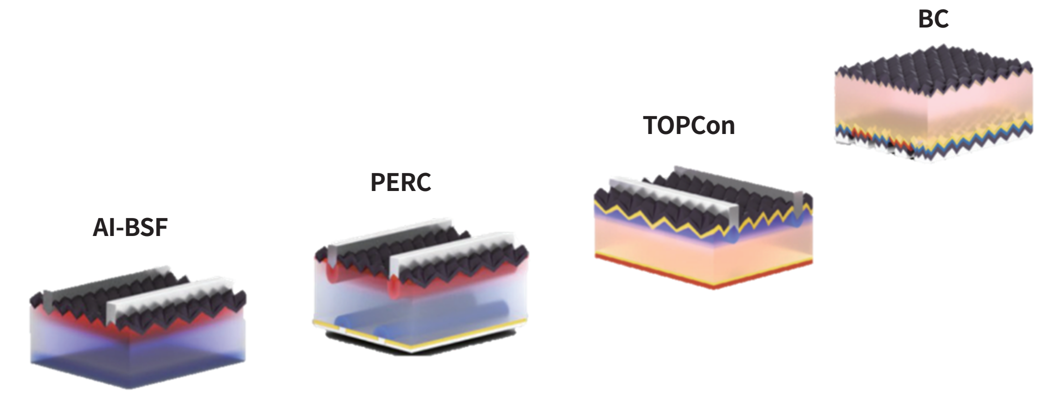
③ Technological process advancements: Cost reduction through multiple technological process paths for BC, such as silver-reduced and silver-free metallization solutions. The introduction of related technological processes will also drive the cost reduction of BC technology.

2.1.5 Empirical analysis of the law of efficiency generation difference

According to the critical point model of technology substitution, when the mass production efficiency of **new technology exceeds the absolute efficiency difference of old technology by 1.5%** and the cost increase is controlled, the inflection point of market technology substitution will be triggered. Given the rapid development of the photovoltaic market and the increasing demands for Levelized Cost of Energy (LCOE), the cycle of technological iteration is further being shortened.

Historical verification:

Technology substitution cycle	Efficiency difference	Iteration speed	Key drivers
BSF→PERC	+2.0%	3 years	Bifacial generation gain (>8% LCOE↓)
PERC→TOPCon	+1.6%	2 years	N-type wafer cost breakthrough (<10%premium)
TOPCon→BC	+1.6%↑	In progress	BC value highlighted, and rapid cost reduction of technology realized



	Aluminum back surface field	Rear surface passivation	Rear surface passivation contact	Dual-zone passivated contact
Technical features	Backside aluminum electrode	Al2O3/SiNx passivation +Al local contact	Tunnel oxygen + doped poly	assivation contact structure in both P and N regions + frontside optical advantage
Laboratory efficiency	~21%	24.5%	26.1%	27.81%

2.2 BC key breakthrough from laboratory to industrialization

Although BC technology has many advantages, its application has been limited to some niche areas for a long time in the past. This was primarily due to the high costs of conventional BC cells and their failure to establish a clear efficiency advantage over other rapidly advancing photovoltaic technologies.

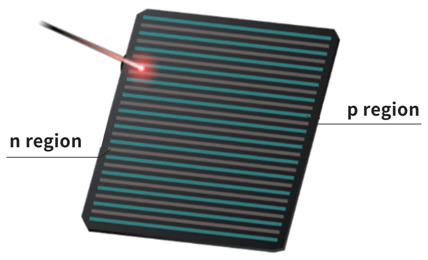
Recent groundbreaking innovations in BC technology have driven substantial reductions in module production costs, significant improvements in mass production efficiency, and rapid enhancement of overall product competitiveness. These technological advancements have established both the technical feasibility and commercial viability for accelerated large-scale manufacturing deployment.

2.2.1 Core process revolution: key breakthrough with 60% cost reduction

a. Laser patterning replaces photolithography

BC cells require high-precision isolation of p+/n+ regions on the backside of the cell to ensure cell availability, because both positive and negative electrodes are on the backside of the cell. In the technological evolution of BC cell, the patterning process is the core hub that determines its transition from laboratory to mass production. Early BC cell research and development relied on semiconductor photolithography technology to achieve high-precision isolation of p+/n+ regions on the backside, but its high cost and complex processseriously restricted the industrialization process.

In 2018, the ISFH in Germany first proposed the solution of "laser doping + rear passivation" and realized the technology. However, the technology was not mature enough to compete with conventional technologies in terms of capacity, cost, and technical capability. In recent years, with the rapid development of laser patterning technology, there have been comprehensive breakthroughs in precision improvement, damage control, and production efficiency. The technology officially entered the mature application phase in 2021. Currently, the mass production of BC cells has fully adopted laser patterning to replace photolithography. This change has significantly reduced the cost of cell equipment and processes while streamlining manufacturing steps. It has truly shifted the manufacturing paradigm of BC cells from "semiconductor-level precision" to "low-cost, mass-producible precision."



Parameter	Photolithography process (traditional)	Laser patterning (BC technology)	Improvement result
Pattern accuracy	±0.5μm	±2μm	Mass production demand satisfied
Equipment investment cost	/	/	Cost↓ by more than 60%
Cost of consumables	Photoresist	No consumables	No consumables
Production cycle time	120 pcs./hour	5,000 pcs./hour	Capacity ↑ by more than 40 times

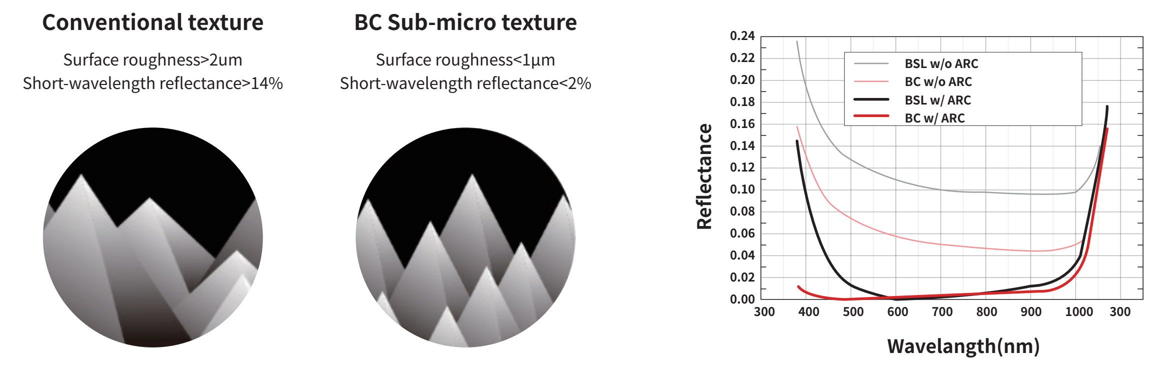
b. Wet process optimization

In the manufacture of traditional BC cells, wet processes (cleaning, etching, removal of amorphous silicon layers, etc.) require 8-10 independent wet process steps (such as RCA cleaning, BOE for PSG removal, acid etching, etc.), which usually account for 30%-40% of the total process, and their duration reaches 50% of the production cycle; at the same time, excessive wet process steps will cause the cell surface microdefects to increase, resulting in increased recombination current and low cell efficiency. The many process steps also result in high equipment investment costs, and consequently BC manufacturing cost can not be effectively reduced.

Process simplification: Since Fraunhofer ISE in Germany verified the feasibility of the mixed acid system in 2019, the continuous innovation and breakthrough of equipment and etching solution manufacturers have assisted comprehensive implementation of the integrated texturing and polishing process, and the number of wet process steps has been reduced from 10 to 3. The process duration is reduced by more than 50%, and the wet process cost is reduced by more than 60%. In addition, with less wet process steps, the surface passivation quality is greatly improved, and the surface recombination current is reduced by more than 40%, effectively ensuring the output conversion efficiency of BC cells.

Textured surface innovation: since BC cell technology has no frontside busbar, the problem of contact between busbar and silicon can be ignored, so submicron pyramid structure can be realized on BC cell textured surface, which reduces reflectance to 9.5% (11% in traditional cell), and color difference ΔE<1.5 (invisible to the naked eye), improving product efficiency and aesthetic degree.

Back Contact (Bc) Solar Technology Development White Paper | **In-depth Analysis of Bc Technology**



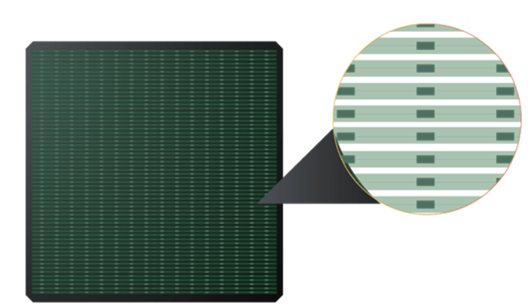
Through the rapid development of laser patterning and the continuous progress of wet process, the production steps of BC cell are reduced from the initial 20+ steps to 12 steps, the overall cell production cost is reduced by more than 60%, and the feasibility of mass production as a mainstream technology is effectively ensured.

2.2.2 Material revolution: production feasibility greatly improved

a. Insulation Adhesive Technology

The core feature of BC cell is that all positive and negative electrodes are integrated on the backside of the cell, forming a **full backside electrode interconnection structure** during circuit soldering. However, since the spacing between p+ and n+ regions is usually only 50-100 μm (traditional cell >1 mm), the risk of electric leakage between electrodes increases sharply, and the passivation layer (SiN_x/SiO_2), polysilicon layer (POLY-Si) and metal busbar need to be integrated on the backside at the same time. The difference in coefficient of thermal expansion leads to interface stress concentration.

The Insulation Adhesive forms a highly reliable insulation barrier between p+/n+ regions, while providing mechanical buffering and process compatibility. It is indispensable in guaranteeing high efficiency and long life of BC cells. Breakthroughs in highly reliable, low-cost insulation glue technology effectively solves the short circuit problem of positive and negative electrodes in BC module encapsulation, and greatly improves the degree of freedom of cell busbar circuit design, solves the problem of soldering efficiency of modules, and effectively reduces the cost of module encapsulation.



Insulation adhesive technology serves as the underlying technical pillar for BC cells to achieve high-efficiency, high-yield, and low-cost mass production.

b. Wafer technology

The emitter, back surface field and metallization of BC cell are all concentrated on the backside, which requires high doping uniformity and purity of wafer. The quality fluctuation of wafer has greater influence on the efficiency of BC cell than on traditional cell technology. Therefore, higher requirements are put forward for minority carrier lifetime, C/O content and resistivity concentration of wafer.

In recent years, various crystal pulling and wafer manufacturers have achieved more effective control of minority carrier lifetime and resistivity range through continuous innovation of crystal pulling technology and iteration of crystal pulling doping technology, providing sufficient and cost-controllable wafers for cell production requirements of BC efficient technology, to ensure that the overall manufacturing process is controllable.

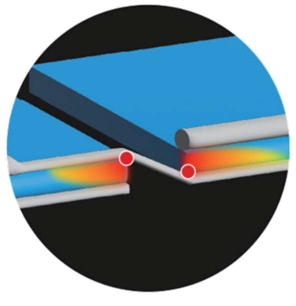
2.2.3 Module encapsulation revolution: Encapsulation with low cost, high efficiency and high reliability

a. Synchronous soldering technology of cell matrix

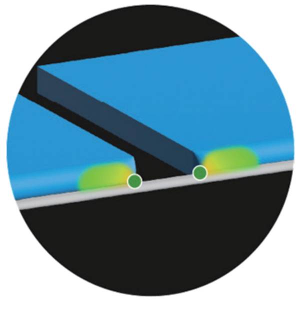
BC cells achieve current collection through interdigitated back contact (IBC) electrodes, a configuration where conventional string ribbon soldering techniques cannot simultaneously meet the stringent requirements for both alignment precision and production throughput efficiency.

Soldering improvement: The maturation of multi-beam parallel processing technology has revolutionized BC module soldering, upgrading from sequential single-cell soldering (conventional method) to simultaneous cell-string soldering. This advancement ensures uniform welding quality while resolving yield and efficiency challenges in BC module production, thereby accelerating the development of high-performance single-side soldering technology for BC applications.

Reliability improvement: Monofacial soldering reduces the stress concentration of the ribbon by 40%, and considerably reduces module load degradation failure and high and low temperature failure risk.



Conventional cell edge stress 50 MPa



BC cell edge stress 26 MPa

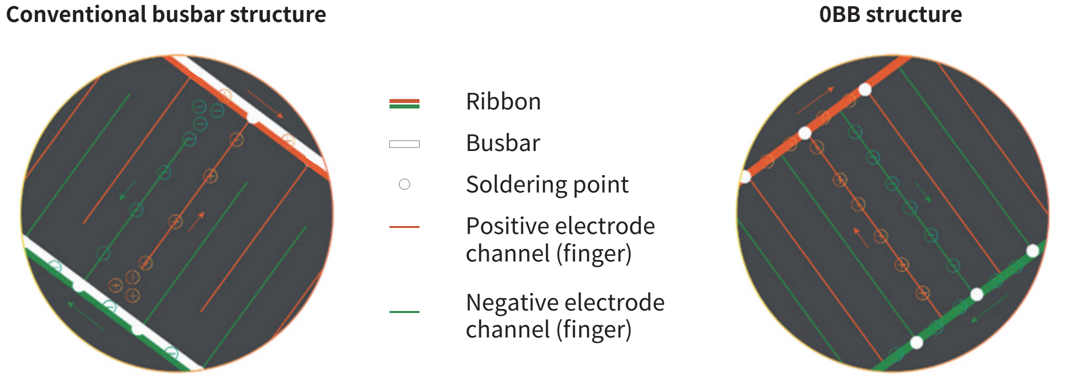
b. 0BB interconnection technology

0BB interconnection technology greatly reduces the lateral current transmission distance and series resistance (Rs) by more than 20% by using dense finger direct solder ribbon connection instead of traditional solder ribbon and cell busbar local soldering method. At the same time, the busbar on the backside is eliminated, and the light utilization ratio of the backside is improved while the manufacturing cost is reduced.

Efficiency/bifaciality improvement: The application of 0BB technology effectively reduces module CTM loss and improves module efficiency by 0.2%. At the same time, due to the increase of soldering points, the metal patterning design on the backside of BC modules is more flexible, and the bifaciality of BC modules can be improved to 75%-80%.

Silver consumption reduction: The silver consumption of cells has been reduced by 30%, further enhancing the manufacturability and cost-effectiveness of BC cells technology.

Reliability improvement: The busbar-free design avoids stress concentration at the busbar-finger soldering interface, and increases the number of module soldering points by 10 times, effectively improving the module's microcrack resistance and reducing the microcrack ratio by more than 50%; in addition, the 0BB fine-line soldering technology offers superior thermal expansion coefficient (CTE) matching at interfaces, delivering enhanced performance in temperature cycling (TC) and damp heat (DH) aging tests.



c. High density encapsulation technology

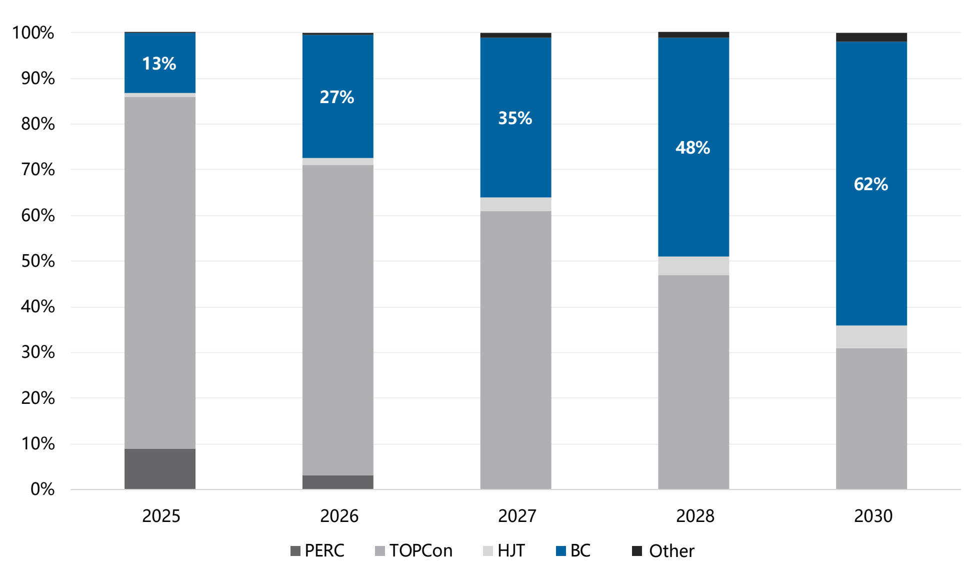
The use of monofacial soldering and 0BB greatly reduces the soldering stress of BC modules in cell chips, providing absolute advantages for high-density encapsulation and providing technical and reliability support for the ultimate improvement of module efficiency.

Parameter	Conventional module	BC module	BC full screen module	Gain
Cell gap	0.8mm	0.5mm	-0.3mm	Area utilization rate~1%
Encapsulation density	93.2%	93.5%	＞94%	

2.2.4 Prediction of intergenerational technology succession: BC's golden decade (2025-2035)

In the development history of PV technology, PERC cell has been the mainstream product for 6 years from 2018 when its market share exceeded that of BSF to 2024 when it was replaced by TOPCon. The whole life cycle is expected to last for 10 years from 2017 to 2026. TOPCon cell entered the market in 2022 and became the mainstream product in 2024. It has entered the mature technology period. BC technology and product are in the growth period. Based on the comprehensive judgment of BC product performance advantages, end user acceptance, iteration pattern of technical route, BC ecosystem and other factors, it is conservatively predicted that the market share of BC modules will continue to increase from 2025, and will increase significantly and will reach 62% in 2030.

Market permeability forecast



Insights of Global Technology Leaders

"BC technology is likely to emerge as the long-term winner, potentially surpassing all other technical pathways to achieve dominance over the next five years and beyond"

——Prof. Martin Green (UNSW)

*Stated Professor Martin Green during an exclusive interview with Red Star Capital Bureau on November 13, 2023.

"From residential rooftop applications to large ground-mounted power stations, BC bifacial technology is constantly evolving to maximize the use of ground reflections. As the industry's most efficient and promising technical route, BC technology will be unstoppable in the next few years."

——Dr. Radovan Kopecek (ISC Konstanz)

*November 20-22, 2024 | The 12th Bifi PV Workshop 2024 · Zhuhai International Summit

"Over the past year, we have seen BC technology become more and more influential domestically. Now, BC technology is recognized as a future direction."

——Professor Shen Wenzhong (Shanghai Jiao Tong University), 2023 China PV Annual Conference Report

*Actual efficiency is constrained by specific operating conditions including: temporal factor, geographic parameters, irradiance characteristics, etc.

Chapter 3
Standard System and Third Party Verification

3.1 International standard framework for testing and certification of PV modules

PV module is the core of solar power system, and its performance and reliability directly affect the electricity generation efficiency, service life and economic return of the system. In order to ensure the consistency and durability of products in different climatic conditions and use scenarios, the International Electrotechnical Commission (IEC) has developed a series of standards and established an international framework for testing and certification of PV modules. These standards provide technical specifications for PV module manufacturers and basic quality assurance for end users, investors and regulators.

The development of all new technologies must meet the requirements of relevant IEC standards, but it is also necessary to focus on and consider the applicability of relevant provisions of the standard according to the technical characteristics of the product.

3.1.1 Core IEC standards for PV module performance test

PV Performance

- IEC 60904-1: Photovoltaic devices Part 1: Measurement of photovoltaic current-voltage characteristics
- IEC TS 60904-1-2: Photovoltaic devices . Part 1-2: Measurement of current-voltage characteristics of bifacial photovoltaic (PV) devices
- IEC 60904-2: Photovoltaic devices- Part 2: Requirements for reference solardevices
- IEC 60904-3:Photovoltaic devices -Part 3: Measurement principles for terrestrial photovoltaic devices and reference spectralirradiance data
- IEC 60904-4: Photovoltaic devices- Part 4: Reference solar devices - Procedures for establishing calibration traceability
- IEC 60904-5: Photovoltaic devices - Part 5: Determination of the equivalent cell temperature of photovoltaic devices by the open-circuit voltage method
- IEC 60904-7: Photovoltaic devices- Part 7: Computation of spectral mismatch error introduced in testing of photovoltaic devices
- IEC 60904-8: Photovoltaic devices - Part 8: Measurement of spectral responsivity of photovoltaic devices
- IEC 60904-9:Photovoitaic devices - Part 9:Perfommance requirements for solar simulators assessment
- IEC 60904-10: Photovoltaic devices-Part 10: Methods oflinearity measurement
- IEC 60891: Procedures for temperature and irradiance corrections to measured l-V characteristics
- IEC 61853-1:Photovoltaic (PV) module performance testing and energy rating - Part 1: Irradiance ano temperature performance measurements and power rating
- IEC 61853-2:Photovoltaic (PV) module performance testing and energy rating - Part 2: Spectral responsivity, incidence angle and module operating temperature measurements

The performance test of the PV module mainly focuses on its electricity generation performance and photoelectric conversion efficiency under different temperature, irradiance, and incident angle conditions, as well as the output power under standard test conditions. These parameters are not only key indicators for evaluating module quality, but also benchmark data for PV system design, procurement, and operation. The following IEC standards are important for the BC PV module performance test:

a. IEC 60904 series: Measurement of PV performance of PV devices

IEC 60904 series provides comprehensive technical specifications for PV performance test of PV modules, ensuring accuracy, repeatability and comparability of test results. This series includes a number of sub-standards, covering measurement methods, spectral definitions, equipment requirements and other aspects, and is the basis for PV performance measurement.

b. IEC 60891: Methods for correcting I-V curves of PV modules under different temperature and irradiance conditions

IEC 60891 I-V curve correction method: It specifies the method for temperature and irradiance correction of I-V characteristic curve of PV device, so as to ensure consistency and reliability of comparison and evaluation of PV device performance under different test conditions. The standard covers four methods, of which Method 1 and Method 2 are based on PV diode models and are the most widely used. In addition, the standard specifies the measurement methods and requirements for the temperature coefficient of PV devices, describing how to determine the parameters related to temperature and irradiance correction.

c. IEC 61853 Series: Performance test and energy rating of PV modules:

IEC 61853 series focuses on the performance test and energy rating of PV modules under actual operating conditions, focusing on evaluating the energy output capability of modules under different irradiance, temperature, and light conditions.

3.1.2 PV module reliability and individual test IEC standard

PV Module Certification and Reliability Tests

- IEC 61215-1: Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1: Test requirements
- IEC 61215-2: Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 2: Test procedures
- IEC 61730-1: Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction
- IEC 61730-2: Photovoltaic (PV) module safety qualification - Part 2: Requirements for testing
- IEC TS 63209-1:Photovoltaic modules -Extended-stress testing - Part 1: Module
- IEC TS 63342: C-Si photovoltaic (PV) modules - Light and elevated temperature induced degradation (LETID)test-Detection
- IEC TS 63397: Photovoltaic (PV) modules - Qualifying guidelines for increased hail resistance
- IEC 62716: Photovoltaic (PV)modules -Ammonia corrosion testing
- IEC 61701:Photovoltaic (PV) modules -Salt mist corrosion testing
- IEC TS 62782: Photovoltaic (PV) modules - Cyclic (dynamic) mechanical load testing
- IEC TS 63126:Guidelines for qualifying PV modules, components and materials for operation at high temperatures

Reliability test of PV modules is intended to evaluate durability and stability under the failure conditions that are likely to occur during initial use or during long-term use, to ensure that efficient electricity generation performance and structural integrity are maintained throughout the lifecycle. These tests detect potential degradation risks of module materials, encapsulation processes, and electrical performance during long-term environmental exposure by simulating accelerated aging processes and extreme stress conditions, including issues such as power degradation, insulation failure, mechanical damage, and chemical corrosion.

a. Photovoltaic (PV) Modules - Dynamic Mechanical Load Testing (IEC TS 62782)

A systematic evaluation method was established by simulating the dynamic mechanical stresses experienced by PV modules during installation and operation. This standard focuses on key failure modes such as cell microcrack risk, interconnection ribbon mechanical fatigue, electrical connection point reliability and edge seal failure.

b. Guidelines for Qualifying PV Modules and Materials for Operation at High Temperatures (IEC TS 63126)

The standard specifies additional test requirements for PV modules operating at elevated temperatures. The test conditions specified in IEC 61215-2 and IEC 61730-2 are based on the assumption that the 98th percentile temperature (T98th) of the module deployment environment is below 70°C. Where T98th is the time that the duration in which the module is expected to reach or exceed that temperature in each year is 175.2 hours. This document defines two temperature classes: temperature class 1 and temperature class 2. The design of these two temperature classes takes into account the operating environment of the module in different installation configurations, where T98th is lower than or equal to 80°C for temperature class 1 and lower than or equal to 90°C for temperature class 2.

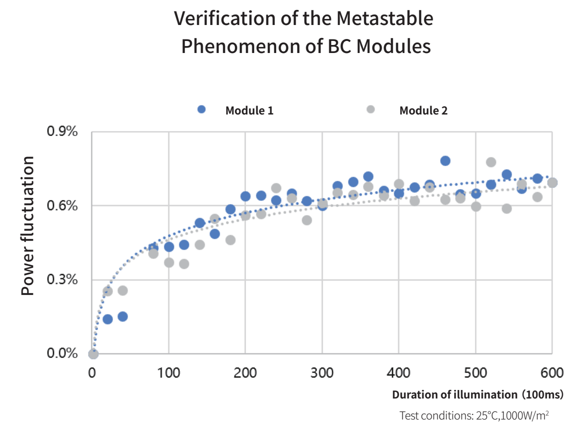
With the continuous development of photovoltaic technology, the efficiency of modules is increasing while their size is growing larger. This leads to changes in current, voltage, capacitance, and load capacity, which pose challenges to the current evaluation standards. Therefore, in addition to following the basic IEC standards, attention should still be paid to the accuracy of the power test, the adequacy of the dynamic load, and thermal failure assessment of current standards. Therefore, in the product power test and reliability verification, according to the technical characteristics of the product itself, the relevant standards should be selected or more stringent standards should be selected based on IEC 60904 series, IEC TS 62782 and IEC TS 63126, to ensure that the product characteristics can be verified in the test.

3.2 BC PV module test measurement standard framework proposal

BC PV module has the general framework that is applicable to the traditional modules and has the optimization requirements for its special structure because of its unique back contact design. At present, the test and measurement of BC modules mainly follow the basic specifications of IEC 60904, IEC 61215 and IEC 61730, which makes it difficult to fully verify the characteristics of BC modules such as high efficiency advantage, microcrack resistance advantage brought by back contact structure, thermal mechanical stability of passivation layer, etc. The following is the recommended framework for test measurements for BC PV module designs:

3.2.1 BC module performance and power test

Due to the difference in cell capacitance, it is necessary to eliminate the capacitance effect before testing the true power of the module in the power test, otherwise, the test power will be lower than the actual power. In the development history of PV process technology, power test methods have been constantly improved according to cell technology upgrades to ensure the accuracy of the power test. The design of the BC module without a frontside busbar significantly improves the photoelectric conversion efficiency, but it is also affected by high capacitance, metastable characteristics, and spectral mismatch, which bring challenges to accurate power measurement and downstream power verification. A non-standard BC module test will cause a large deviation in module test power. Through comparison of different methods, TÜV Rheinland has found that the module power difference can reach 0.3%-1%.To fully evaluate its performance and electricity generation parameters, the required special test and measurement scheme is as follows:



a. BC module electrical parameter output characteristic test

Output characteristic measurements for BC modules based on IEC 60904 series standards. The main tests include:

① STC measurement based on IEC 60904-1 and measurement error of the BC module caused by different measurement methods.
② Integrated power calculation of BC bifacial PV module based on IEC 60904-1-2.
③ BC PV module tracing method and system management based on IEC 60904-2 and IEC 60904-4.
④ Spectral response measurement and spectral mismatch factor analysis of BC PV module based on IEC 60904-7 and IEC 60904-8.
⑤ Capacitance-voltage characteristic measurement of BC PV modules.
⑥ Measurement of BC PV module metastable state characteristics and the elimination methods.

b. Standardized measurement specifications and reference module calibration for BC Modules

Based on empirical output characteristics of BC modules, it is required to establish a dedicated technical specification for mass production line measurements, as well as redefining: The calibration transfer methodology for BC reference modules and solar simulator verification procedures.

c. BC module measurement system control

To ensure the accuracy of the BC module power measurement, a series of calibration and verification steps need to be executed according to the calibration characteristics of the BC module, to ensure the accuracy and consistency of measurement from benchmark establishment to production test. Based on IEC standards and practices, the reliability of the BC module performance measurements is ensured through full chain quality control. The contents include reference module calibration, qualification training of measurement personnel, evaluation of measuring system, measurement process control, and periodic power verification.

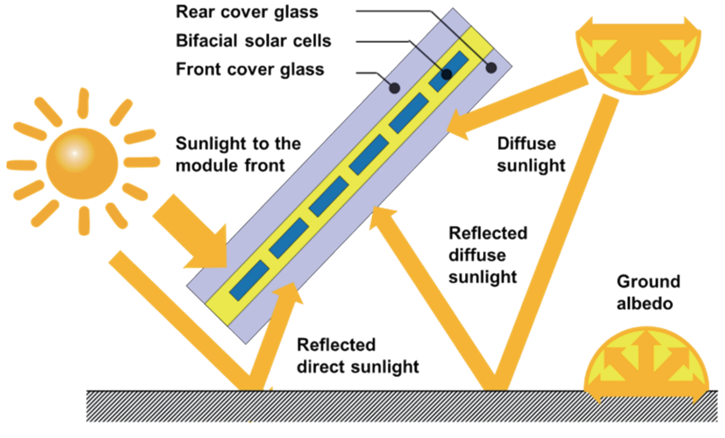
d. Recommendations for comprehensive power test standards for bifacial modules

In the context of the rapid development of the PV industry, various technical routes continue to emerge, and how to evaluate the electricity generation performance of bifacial modules has caused many discussions in the industry. We believe that we must return to the essence of science and interpret it in conjunction with the actual project.

IEC 61215 (2021 edition) clearly defines parameters related to bifacial modules. The bifaciality factors, i.e. the ratio of the electrical parameters of the frontside and backside of the bifacial module under standard test conditions (STC), include the short-circuit current bifaciality factor, the open-circuit voltage bifaciality factor and the maximum power bifaciality factor. The term "bifaciality" often used in the industry refers to the maximum power bifaciality factor.

The bifaciality factor of the bifacial module is the ratio of the electricity generation efficiency of the backside and that of the frontside measured in the laboratory. The higher the factor, the closer the power generation capacity of the backside is to that of the frontside.

To evaluate the combined power generation capacity of a bifacial module, irradiance needs to be considered in addition to the bifaciality. IEC 61215 gives the reference irradiation condition for the nameplate calibration of bifacial modules - "bifacial nameplate irradiance (BNPI)", i.e. the front side of the module receives an irradiance of 1,000 W/m², and the backside receives an irradiance of 135 W/m² at the same time (the backside irradiance accounts for 13.5% of the frontside). Except for the irradiance, other test conditions are consistent with STC.



Regarding the bifacial irradiation test method for bifacial modules stipulated in the IEC standard, the IEC standard considers that the BNPI conditions can cover most of the terrestrial application scenarios of PV modules. However, from the actual project situation, module backside power generation gain = backside irradiation gain x bifaciality x performance ratio, and the vast majority of the project backside irradiation accounted for the total irradiation is much lower than 13.5%. According to simulations using PVsyst and actual project performance, the rear-side gain of bifacial modules varies significantly across different scenarios such as water surfaces, grasslands, and sandy areas. On average, the rear-side irradiance gain is approximately 5%. It is recommended that investors in the photovoltaic industry or power station owners take a scientific view of the rear-side gain situation.

If testing and calibration are conducted solely in accordance with IEC standards, it may have an impact on the design of actual projects and the assessment of power generation. Therefore, this white paper suggests that in comprehensive power measurement, different testing schemes should be established based on the classification of actual project scenarios. The rear-side irradiance should be selected within the range of 20 W/m² to 135 W/m² according to the specific scenario.

3.2.2 BC module reliability and durability verification

The back contact structure of BC modules has the advantages of of reducing microcracks and improving durability, but special reliability tests are required to verify their performance in extreme environments. Based on IEC 61215, IEC 61730, IEC TS 62782, IEC TS 63209-1 and IEC TR 63279, the reliability test sequence applicable to BC modules includes extended thermal cycling, damp heat and PID resistance tests, thermal mechanical stress integrated tests, high and low temperature UV aging tests and shading resistance tests.

3.2.3 BC module electricity generation and application scenario suitability test

Because some characteristics of BC technology cannot be fully tested and demonstrated in the laboratory, and the test results cannot be accurately applied to outdoor actual operation modeling, it is necessary to combine outdoor empirical testing and scenario-based comprehensive testing to better verify the power generation capability and reliability advantages of BC modules in practical applications.

a. BC module outdoor empirical testing

Outdoor demonstration tests were carried out on BC PV modules used under different climatic conditions. According to IEC 61215 and IEC 61853 series standards, the effects of factors such as bifaciality, different irradiance, temperature, incident angle and spectrum on outdoor power generation of BC PV modules were analyzed, and the proportion of different factors in electricity generation was quantified.

b. BC module environmental suitability test

For the application of BC modules in DG and ground-mounted power stations, evaluate the reliability and performance of BC PV modules in different environments and functional applications, including offshore, desert, anti-shading applications, high system voltage applications, etc.

3.2.4 BC Product Quality Standard System

The mass production of new technologies requires unified industry standards for product/material quality to guide manufacturing execution and customer product selection, ensuring that new technologies develop rapidly and meet high standards. Currently, mainstream BC companies are actively promoting the establishment and improvement of quality standard systems for products and materials, accelerating the standardization of BC quality.

The group standards "Silver Paste for Backside Silver Paste Sintering" and "Back-Contact Photovoltaic Cells," released on March 5, 2025, have laid the foundation for standard references in the selection of pastes and cell manufacturing for BC technology. The introduction of the 0BB (Zero Busbar) new technology also requires differentiated standards for guidance. The industry has reached a consensus on the technical characteristics and quality control standards for 0BB welding and has already begun to promote the release of the group standards "Busbar-less Photovoltaic Modules" and "Crystalline Silicon Back-Contact Photovoltaic Modules". These efforts aim to provide reference criteria for module production and customer selection.

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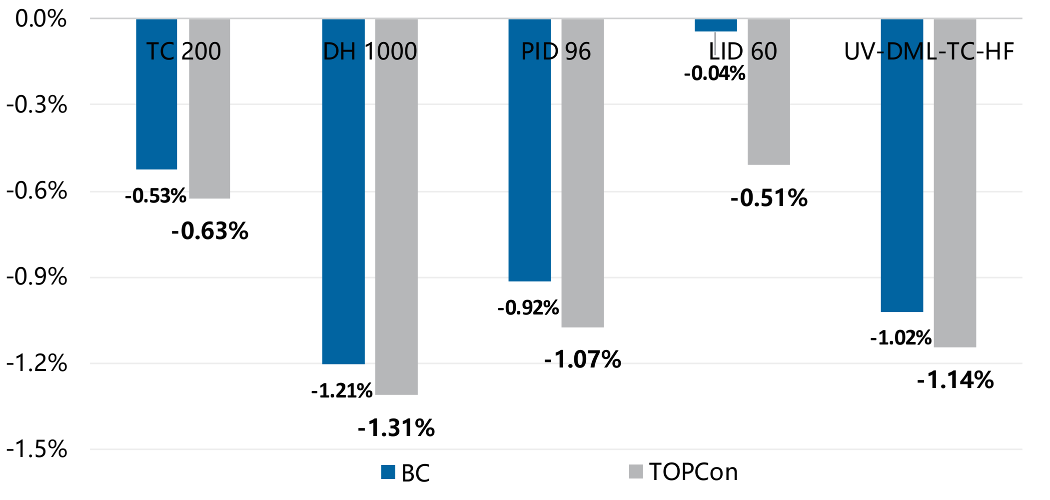
3.3 Test data authoritative release

BC modules perform better than TOPCon modules in reliability tests conducted by third parties on average, and BC modules have also won the Rhine 2024 Quality Win China bifacial module Reliability Award. The reliability test degradation is reduced by more than 10% on average compared with TOPCon products. These results provide a solid guarantee for the long-term stable operation of customer power stations.

TÜV Rheinland: Comparison of IEC test results



3.3.1 Temperature cycle test

Thermal cycle tests are used to evaluate the durability and performance stability of modules under extreme temperature variations. This test simulates the actual operating environment of the module under day and night temperature differences, seasonal changes or extreme weather conditions to verify that it can withstand severe temperature fluctuations without performance degradation or physical damage. Within the temperature range of -40°C to 85°C, after 200 temperature cycle tests, the degradation of BC modules is reduced by 15.8% compared to TOPCon modules. (Test data is from TÜV Rheinland)

BC module: the average power degradation rate is 0.53%

TOPCon: the average power degradation rate is 0.63%.

3.3.2 Damp heat test

The module damp heat test evaluates the performance degradation and potential failure mode of PV modules in a long-term damp heat environment by simulating the effect of a high temperature and high humidity environment on PV modules. After 1,000 hours of continuous testing under the dual conditions of 85°C temperature and 85% humidity, the degradation of BC modules is 7.6% lower than that of TOPCon modules. (Test data is from TÜV Rheinland)

BC module: the average power degradation rate is 1.21%.

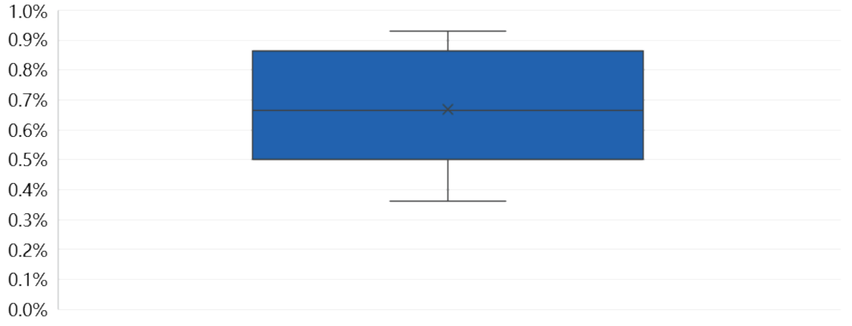
TOPCon: the average power degradation rate averages 1.31%.

In November 2023, China Electric Power Research Institute (CEPRI) conducted a one-year natural exposure test on BC modules and PERC modules in a hot and humid environment in Hainan. Under the same test conditions, the electrical performance parameters of BC modules were tested after one year, with an average power degradation of 0.67%, far lower than 1%. This fully demonstrates the reliability of BC modules in hot and humid environments. (Test data from CEPRI)

PERC module

BC module

Degradation of BC modules in damp heat environment



3.3.3 PID test

PID test is a test to evaluate the performance degradation of PV modules under long-term high voltage, high temperature and high humidity environment. It is a solar cell module under the action of high voltage for a long time, so that there is leakage current between the glass and the encapsulating material, a large amount of charge is accumulated on the surface of the cell, resulting in reducing passivation effect on the surface of the cell, easy to make the carrier recombination so that the module performance is lower than the design standard. After 96 hours of PID testing under high-temperature and high-humidity conditions, the degradation of BC modules is 14% lower than that of TOPCon modules. (Test data is from TÜV Rheinland)

BC module: the average power degradation rate is less than 0.92%.

TOPCon: the average power degradation rate is 1.07%.

3.3.4 LID degradation

The LID degradation test is a test used to evaluate the light induced degradation of PV modules. LID refers to the phenomenon that the electrical performance of PV modules will gradually decline under sunlight. This test usually uses a solar simulator as a piece of test equipment to observe the performance changes of PV modules under long-term illumination by simulating sunlight irradiation. After exposure to 60 kWh of light irradiation, the degradation of BC modules is 92% lower than that of TOPCon modules. (Test data is from TÜV Rheinland)

BC module: the average power degradation is 0.04%.

TOPCon: the average power degradation rate is 0.51%.

3.3.5 UV+DML+TC+DH

This test is a comprehensive reliability test program that combines ultraviolet irradiation (UV 15 kWh), dynamic mechanical loading (DML 1000), temperature cycle (TC 50) and humidity freeze (HF 10) tests to comprehensively evaluate the performance and durability of products under various environmental factors. After this sequence of tests, the degradation of BC modules is reduced by 10.5% compared to TOPCon modules. (Test data is from TÜV Rheinland)

BC module: the average power degradation rate is less than 1.02%.

TOPCon: the average power degradation rate is 1.14%.

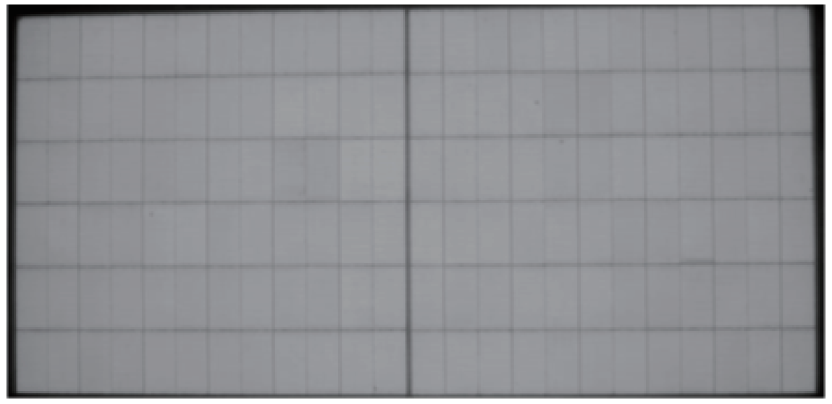
3.3.6 Wind tunnel test

PV wind tunnel test is the most direct means to evaluate the wind resistance performance of PV modules. By simulating the actual wind field environment, wind loads are applied to PV modules and systems to test their stability and safety under different wind speeds.

Under the witness of the international authoritative third-party testing organization, BC products (size: 1134mm × 2382mm) successfully passed the wind tunnel test up to 64.4 m/s (equivalent to scale 18 super wind), refreshing the wind tunnel test industry record. After the test, the BC module did not suffer any damage, the frame did not deform, and there was no performance degradation or EL microcrack. The reliability of BC modules in extreme wind environments far exceeds that of conventional PV modules in the industry.

After the wind tunnel test, the degradation of BC modules and the results of the EL test were evaluated. (Test data is from TÜV Süd)

Test module	Power before test	Power after wind tunnel test	Wind tunnel test degradation
BC module	641.35W	640.17	0.18%



3.3.7 Scenario-based certification test

At present, with the gradual strengthening of customers' requirements for scene adaptability, a large number of scene-based certifications have been launched in the industry, and the current cell technology and encapsulation technology of BC module products have strong adaptability to offshore PV scenarios (monofacial soldering reliability, cell UV resistance, encapsulating material aging resistance, etc.), applicable to customers in the offshore PV scenario greatly improve the overall reliability of the project; BC module products have also obtained the "deep blue ocean environment" related certification jointly formulated by China Huaneng Clean Energy Research Institute and CPVT, and have excellent results in UV, DH, etc.

3.4 Carbon footprint and sustainable development certification

With the rapid development of PV industry and international attention to global warming, carbon emission in the whole life cycle of PV industry chain is becoming the focus of global governments, enterprises and research institutions. Some countries are establishing international green trade barriers based on product life cycle assessment and carbon footprint, in order to support the application of low-carbon emission modules within their own countries. The carbon footprint is gradually becoming a key competitiveness factor for photovoltaic modules in the global market.

Life cycle assessment (LCA) is a quantitative and qualitative method to analyze the environmental impact of different product life cycle processes, and comprehensively assess the environmental impact of products in terms of greenhouse gas emissions, water consumption, energy consumption, etc. during the life cycle of products. Carbon Footprint of Products (CFP) is an environmental impact assessment in LCA, which measures the direct or indirect greenhouse gas emissions of a product during its life cycle stage.

At present, many countries have introduced carbon footprint evaluation standards for PV modules, such as: France, South Korea's PV module carbon footprint certification requirements; Sweden, Italy's PV module environmental product declaration (EPD) requirements; EU PV module specific evaluation specifications (Product Environmental Footprint Category Rules, PEFCR), etc.

3.4.1 France's carbon footprint

Scope: Certification of carbon emissions from raw materials to the factory of PV modules, only in France.

Suitability: CRE (French Energy Regulatory Commission) mandatory requirements of more than 500kW PV projects, bidding requires a carbon footprint certificate, ECS (Evaluation Carbone Simplifiée).

Interpretation: In the carbon footprint rules, the following formula is used to calculate the sum of the carbon emissions caused by the following products manufactured by the PV production chain under a PV power station capacity of 1 kWp to assess the environmental impact of PV modules.

3.4.2EPD

In recent years, more and more enterprises require imported PV products to provide product EPD declaration, EPD certification has become an important means to deal with international trade barriers, PV field is generally based on International EPD, EPD Italy and EPD Norge.

	Name	Coverage industry	Country
	EPD Italy	Comprehensive	Italy
	International EPD	Comprehensive	Sweden
	EPD Norge	Comprehensive	Norway
	EPD Ireland	Comprehensive	Ireland
	IBU EPD	Building materials	Germany
	Bau EPD	Building materials	Austria

3.4.3 South Korea's Carbon Footprint

South Korea released the Operation Guide for Low-Carbon Solar Cell Module Product Support in June 2020 to promote eco-friendliness of module products and reduce global greenhouse gases. There are four levels of carbon emissions.

Rating	Carbon emission	Incentive Application Method	
		RPS Selective Bidding	Government-supported projects
I	- 630 kg.CO_2 /kW or less	Evaluate carbon footprint as a major factor when bidding for new generation (utility) business-differentiate scores by grade	①Priority subsidy support for carbon footprint certification products ②Support according to different subsidy proportion of grade
II	- 630 to 670kg.CO2/kW		
III	- 670kg.CO2 /kW Exceeded		
IV	- 730kg.CO2 /kW Exceeded		

Similar to France's carbon footprint, the analysis of product life cycle carbon emissions is based on the life cycle assessment standard ISO 14040/14044.

The assessment scope is from cradle (raw material production) to gate (module delivery), and the carbon emission of frame shall be considered at the module end, regardless of loss and damage coefficient.

Different from ECS in France, South Korea's current rules require LCA for the whole industry chain to reduce the total carbon footprint, and LCA values cannot be used in individual links, so default values are used in all stages.

3.4.4 ISO14067

ISO 14067 carbon footprint certification is not mandatory in European countries for import or tender certification, but some customers may need to identify carbon emissions from their supply chain in their social responsibility reports, which will require module suppliers to provide an ISO 14067-based carbon footprint assessment for their products.

Due to its ultra-high cell efficiency and advanced encapsulation technology, BC technology produces modules with a power of about 6% higher than TOPCon under the same consumption and energy consumption, and reduces carbon emissions by about 6% year-on-year. The selection of BC modules for construction projects in areas with high carbon footprint requirements will bring higher competitiveness to the project and also take a step towards true "zero carbon" energy.

Chapter 4

BC Technology Module Core Performance Advantages and Parameters

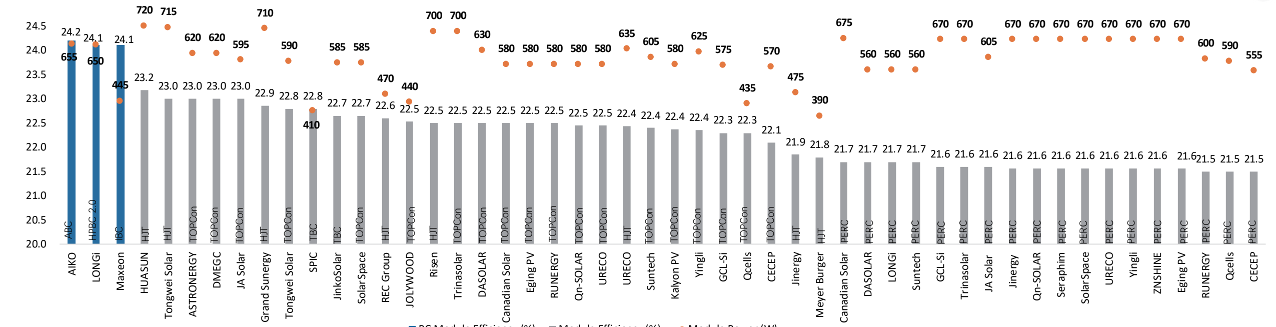
4.1 High module efficiency

After in-depth technical validation and process iteration of the industrialization of the BC technology, the current BC cell mass production system has achieved comprehensive process solidification. The average conversion efficiency of BC technology cell production batches reaches more than 27%, achieving an absolute efficiency gain of 1.6 percentage compared with mainstream TOPCon cells. It is particularly worth noting that, in addition to the inherent advantage of cell efficiency, the application of new technologies such as the 0BB (zero busbar) soldering technology is also continuously improving the CTM (Cell-to-Module) loss of the BC module. This comprehensively drives the power output of the mainstream module size (1134mm × 2382mm) to achieve a significant gain of more than 35W compared with the traditional TOPCon technology. The mass production efficiency of BC modules has now fully exceeded 24%.

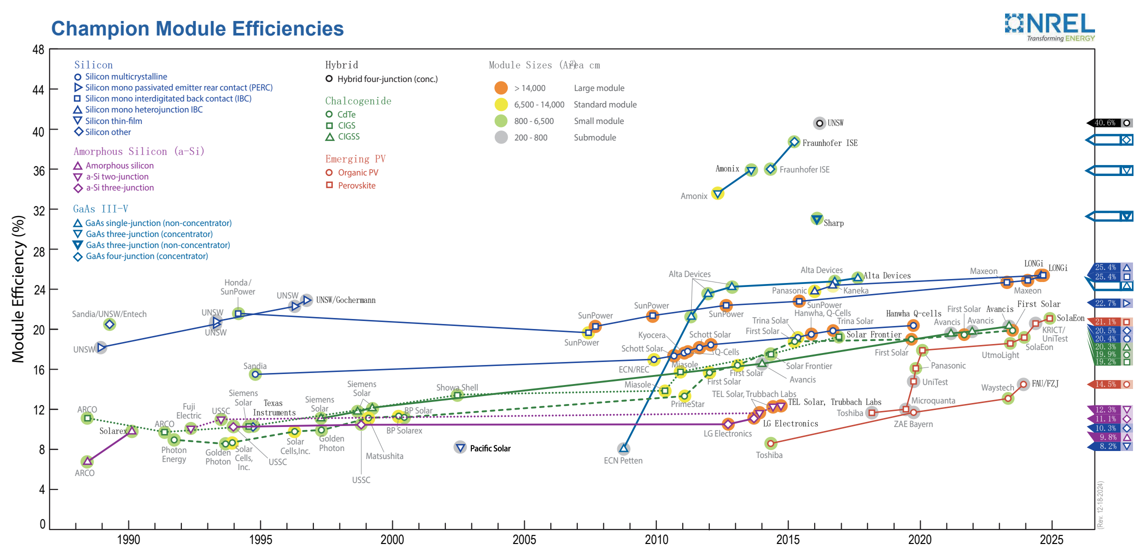
The CGC top runner certification system certifies that BC modules are currently the only PV module technology capable of mass production efficiency of more than 24%.

CGC certified module power/W	655	660	665
CGC certified module efficiency	24.25%	24.43%	24.62%

According to TaiyangNews' statistics on the efficiency of modules shipped in large quantities worldwide, as of the end of March 2025, BC mass production shipped modules with an efficiency of more than 24%[8], leading other technologies in the world.



The breakthrough technology has been certified by international authorities, BC module with a conversion efficiency of 25.4%[9] to refresh the world record of crystalline silicon module, marking the official establishment of BC technology as a new generation of efficient PV technology.



In addition to the absolute lead in front-side efficiency and power, BC bifacial modules also significantly outperform TOPCon technology modules in terms of comprehensive power and efficiency . Based on the simplified formula of the comprehensive power test method of the current bifacial module: front-side power + front-side power * bifaciality * backside irradiance, the mainstream bifaciality of BC module is 75%, and the bifaciality of TOPCon is 80%. As mentioned above, when considering the comprehensive power, attention should be paid to the power conversion on the backside according to the actual project environment. According to the mainstream scenario of the utility project, it is suggested to calculate the comprehensive power according to 30 W/m2 (water surface), 60 W/m² (grassland), and 100 W/m2 (sand) on the back:

Scenario1：Scenario 1: Water surface scenario (non-floating) BC module integrated power is 34.9W higher than TOPCon integrated power, the increasing ratio is 5.4%
BC comprehensive power = 660+660*75%*0.03=674.9W
TOPCon comprehensive power = 625+625*80%*0.03=640W

Scenario 2: The BC module comprehensive power of grassland scenario is 34.7W higher than that of TOPCon, and the increasing ratio is 5.3%;
BC comprehensive power = 660+660*75%*0.06=689.7W
TOPCon comprehensive power = 625+625*80%*0.06=655W

Scenario 3: The BC module comprehensive power in the desert scenario is 34.5W higher than that of TOPCon, the increase ratio is 5.1%;
BC comprehensive power = 660+660*75%*0.1=709.5W
TOPCon comprehensive power = 625+625*80%*0.1=675W

In summary, whether it is only the front-side power or the comprehensive power, the BC module power is more than 5% higher than that of TOPCon products.

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4.2 High power generation capacity

4.2.1 Better temperature coefficient

The power temperature coefficient of a PV module is a key indicator of the power loss of the module when the temperature changes, usually expressed as a percentage of the STC output power. The temperature coefficient of solar cells is mainly affected by material characteristics. The temperature coefficient of Pmax is determined by the open-circuit voltage coefficient, the current temperature coefficient, and the fill factor temperature coefficient. The open-circuit voltage has the most significant effect on the temperature coefficient, and its contribution to the temperature coefficient of module power is as high as 80-90%. BC cell adopts bipolar passivation technology, the open-circuit voltage of the cell can reach more than 750 mV, while the current mainstream TOPCon only passivates one pole, and the open-circuit voltage is about 730 mV.

$$\beta_{Voc} = -\frac{V_{g0} - V_{oc} + \gamma\left(\frac{kT}{q}\right)}{T}$$

$$\beta_{Pmax} = \beta_{Voc} + \beta_{Isc} + \beta_{FF}$$

According to the current mass production modules temperature coefficient test, BC module temperature coefficient can reach -0.26%/°C, TOPCon module temperature coefficient is-0.29%/°C, so BC temperature coefficient is better, a better temperature coefficient is conducive to the increase of electricity generation.

According to IEC TS 63126, the operating temperature of PV modules can reach more than 50°C in the main investment areas of PV power stations in the world. In the hot season of high high-temperature area, when the outdoor temperature is about 40°C and the actual operating temperature of the module reaches 70°C, the power output of the BC module is higher than that of the traditional module by more than 1.3%.

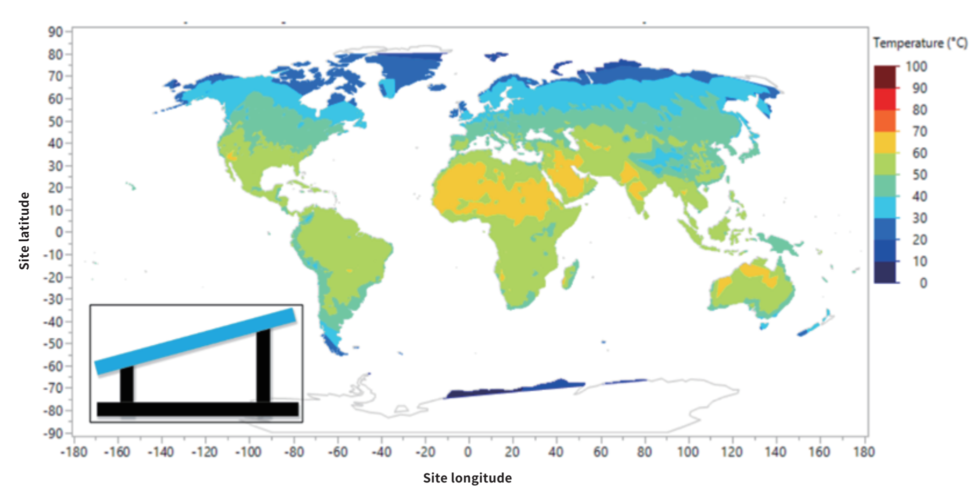
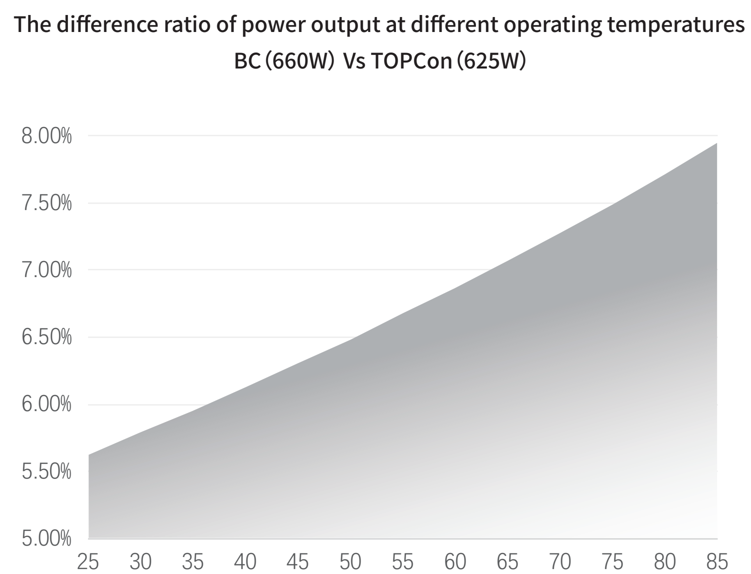


Figure A.3 - 98th-percentile temperature for an open-rack, or thermally unrestricted, glass superstrate,polymer backsheet module

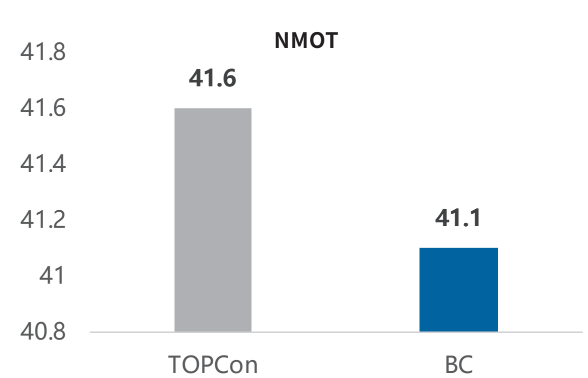


4.2.2 Lower operating temperatures

PV modules absorb light (except reflected and transmitted light): part of it is used for PV power generation; the other part is absorbed (about 70%), which is manifested as an increase in thermodynamic temperature, that is, light absorption and heating.

For modules of the same area, the higher the power, the smaller the light absorption and heating, and the lower the operating temperature. BC module efficiency is higher than TOPCon module by more than 5%, so the ratio of light to electricity increases by 5%, the ratio of light to heat will be reduced synchronously, through calculation BC module operating temperature is lower than TOPCon by more than 0.5°C

Module type	Light intensity W/m²	Area/ m²	Total light intensity/W	Module reflectance/%	Absorbed light intensity of module/W	Module power/W	Light absorption heating power/W	Temperature higher than ambient/°C	Module operating temperature/°C
TOPCon	1000	2.7	2700	7	2511	625	1886	30	55
BC	1000	2.7	2700	7	2511	660	1851	29.5	54.5

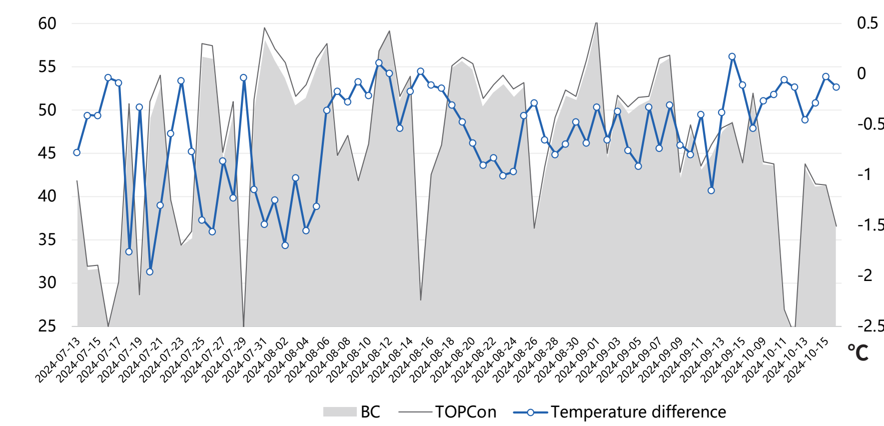


-0.5°C

The NMOT temperature BC module VS TOPCon module

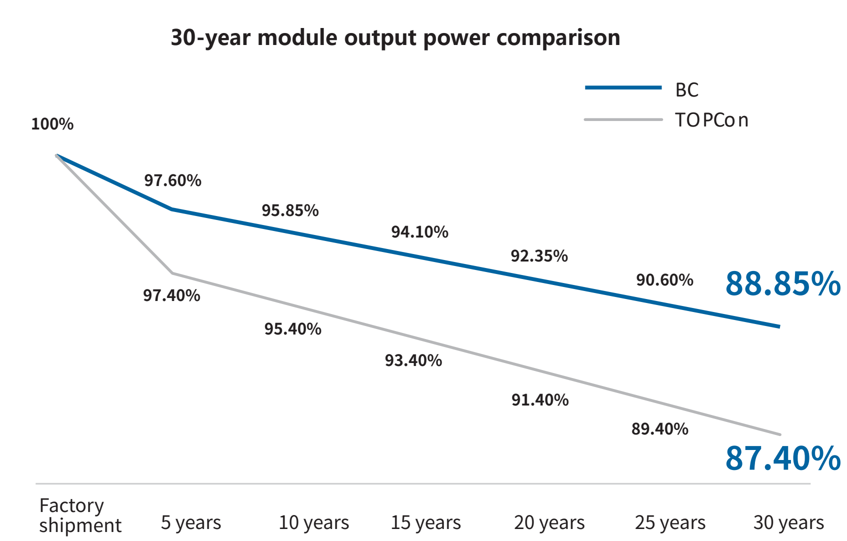
According to the specifications of NMOT test in IEC, the NMOT test data of BC module and TOPCon module by the third party testing company are as follows. It can be seen that the NMOT temperature of BC module is 0.5°C lower than that of TOPCon, further verifying the low operating temperature characteristics of BC module.

Long-term monitoring of the temperature data of the module during actual outdoor operation also demonstrates the performance of BC modules at low operating temperatures. The following figure shows the comparison of the hourly average operating temperature of BC and TOPCon modules during outdoor operation for 3 months. The data shows that the operating temperature of BC modules is significantly lower. In July, when the temperature is higher, the temperature difference between BC and TOPCon can reach -1°C.



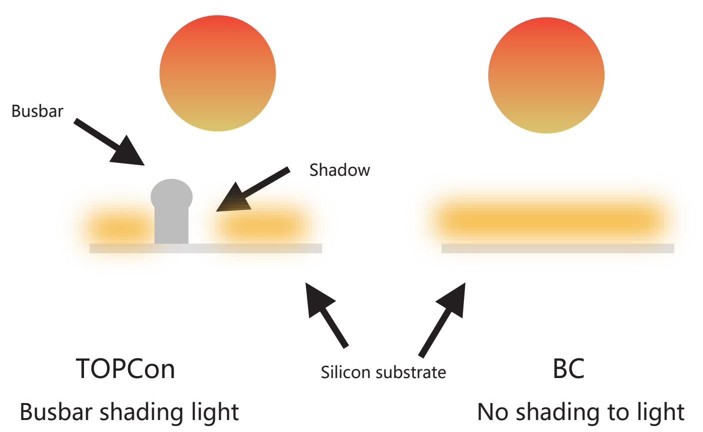
4.2.3 Better degradation resistance

The decrease of module operating temperature is helpful to reduce the long-term aging speed of encapsulation film and metal (such as encapsulation film delamination, yellowing, soldering stress, strength deterioration, etc.). The typical activation energy of crystalline silicon modules is 0.6–1.1 eV. This corresponds to a power degradation rate that increases by 1.5–2 times for every 10°C rise in module temperature[9]. The mainstream BC modules in the current market have better long-term degradation performance, which can achieve 0.35%/year degradation guarantee, which is better than 0.4% of TOPCon modules. The degradation trend in the 30-year life cycle of the modules is as follows. At the 30th year, the BC modules reduce the degradation by 1.45% relative to TOPCon modules.



4.2.4 Better incident angle modifier (IAM) performance

BC module significantly improves the photoelectric conversion efficiency under low incident angle illumination conditions through innovative structural design. Its core technical advantages are mainly reflected in three aspects: firstly, the light-receiving surface of the cell adopts zero-busbar design, which completely eliminates the diffraction loss of the traditional grid line structure to incident light; secondly, the submicron texture process and anti-reflection coating design with better transmittance on the frontside of the cell effectively improve the light transmission rate at a high bright incident tilt angle; furthermore, the Fresnel reflection loss is effectively reduced by optimizing the thickness parameters of the front encapsulation film through precision optical simulation. Laboratory demonstration shows that BC modules exhibit significant power generation advantages over traditional PERC derived technology products such as TOPCon under low radiation angle conditions with incident angles greater than 60°, with an incident angle modifier (IAM) increase of up to 2%, especially in dawn and dusk periods and oblique light conditions at high latitudes.



4.2.5 Remarkable anti-shading performance

In complex PV application scenarios, the non-uniform irradiation distribution caused by the dynamic shadow shading effect among arrays (including vegetation, poles and towers, mutual shading of modules, etc.) will lead to double power losses in modules: direct radiation degradation and electrical mismatch resulting from the operation of bypass diodes. Traditional modules adopt a centralized bypass protection architecture. When a local cell string is shaded, the forced conduction of the corresponding bypass diode will cause the entire string circuit to stop generating electricity, and the performance ratio will decline in a stepwise manner.

BC modules have achieved a cell-level intelligent protection mechanism through a revolutionary intrinsic parallel circuit design. Its unique distributed micro-grid structure enables each cell unit to have an autonomous bypass function. When a single cell is shaded, only the local equivalent diode is triggered to conduct, forming an independent current path, without the need to activate the string-level protection device. This innovative architecture ensures that the shading loss is strictly controlled within the physical area of the shaded unit. Compared with traditional modules, it can reduce the shading power loss by 34% (based on experimental and empirical data).

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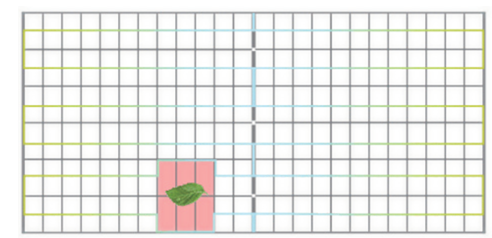
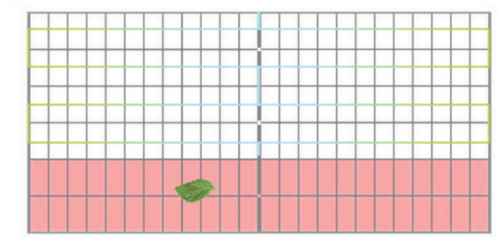
The comparison tests under shading conditions show
(50%-100% half-cut shading gradient experiment)

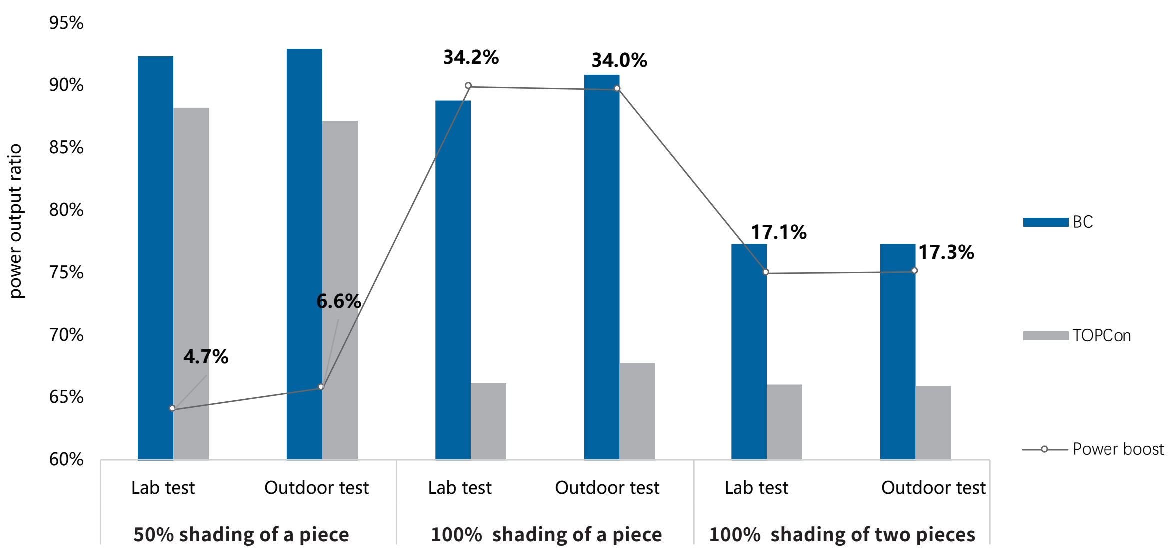


BC module



Other modules

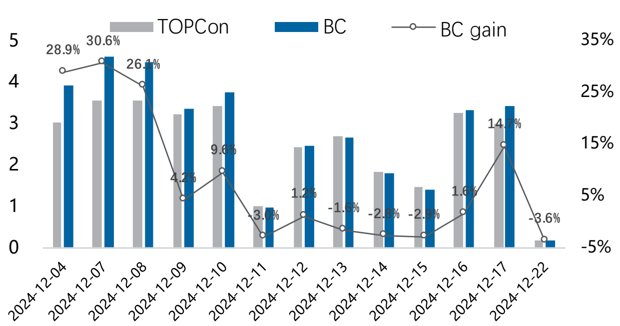
In laboratory tests, the power performances of BC modules and TOPCon modules when 50% and 100% of one half-cut and two half-cuts are shaded respectively are as follows. It shows that when a single cell is shaded, the power change of BC modules is relatively small, while the TOPCon products experience a significant power drop. The anti-shading performance of **BC modules is improved by 34% compared with that of TOPCon modules.**



This difference stems from the refined energy management of the shading effect by BC technology. By reconstructing the carrier transport path, it transforms the "string-level failure" of traditional modules into "point-level failure", enabling the system to maintain an effective power generation area of over 93%. This feature is especially applicable to scenarios with complex shadow movements, such as in high-latitude regions and mountain power stations, and it can significantly increase the annual average effective power generation duration of the system.

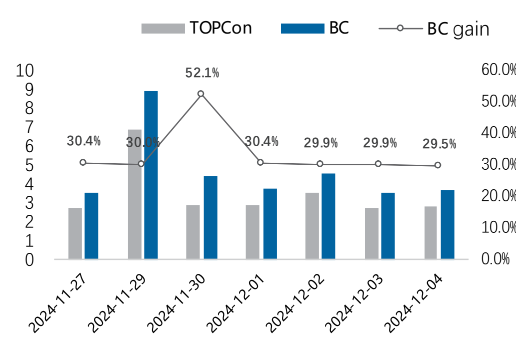
Under the supervision of third-party certification bodies,
the BC modules have significant advantages in power generation under shading conditions.

Comparison of power generation under the shading of columns
in the CGC Hainan Demonstration Base



Column shade

The electricity generation per watt is increased by 11% compared with that of TOPCon.



Partial shade

The electricity generation per watt is increased by 33% compared with that of TOPCon

Thanks to their excellent anti-shadow shading performance, the BC modules have also been recognized by third parties, and have obtained the Class A certification in the anti-shadow shading test by TÜV Rheinland.

Comparison between the shading power of TÜV Rheinland BC modules and the simulated shading loss of TOPCon modules:

BC shading power loss	4.15%	5.12%
TOPCon shading power loss	12.93%	11.07%

8×8 cm shading of a single cell

4.3 High reliability

4.3.1 Good microcrack resistance

Through dual innovations in structural design and manufacturing process, BC modules have systematically resolved the risks of microcracks and cell fragments in PV modules during construction, installation, under mechanical loads, and in long-term operation. The combination of the full-backside soldering technology and the stress-optimized structure provides the underlying technical guarantee for the high reliability of the PV system throughout its entire life cycle, significantly reducing the O&M costs and prolonging the power generation revenue cycle.

a. Innovative soldering procedure design

Based on the full-backside electrode layout, BC modules adopt the monofacial soldering procedure and the "I"-shaped continuous soldering technology, breaking through the limitations of the traditional Z-shaped soldering. This technology achieves a leap in reliability through the following core advantages:

①The linear ribbon path eliminates stress concentration zones and reduces the risk of edge fragmentation.
②The soldering contact area is greatly expanded, forming a high-strength mechanical connection interface.
③The tensile and shear resistance of soldering spots is significantly superior to that of traditional processes.

b. Enhanced mechanical load performance

BC modules reconstruct the stress distribution through digital topology optimization technology and combine with the 0BB whole-string soldering system to achieve precise process control, thus realizing the following core characteristics:

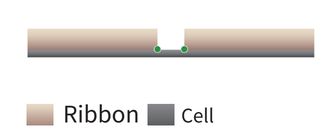
①The retention rate of the connection interface strength in extreme temperature environments leads the industry.
②The degradation rate of residual stress under dynamic loads is reduced to 40% of the industry average level.
③The anti-fatigue performance has been improved to more than three times that of conventional modules.

The BC module enhances its resistance to deformation under complex loads significantly through an innovative structural reinforcement solution and a precise lamination process. Its unique stress-distribution architecture can effectively cope with snow load, wind load, and asymmetric external forces during construction, thereby minimizing the probability of micro-cracks. Moreover, it maintains stable structural integrity under dynamic load conditions, ensuring reliability throughout the entire lifecycle from installation to operation and maintenance.

Combined with the EL testing results, BC modules can reduce the risk of microcracks by approximately 87%. The TÜV SÜD conducted enhanced wind tunnel tests and a 1,500 Pa enhanced dynamic load test (1.5 times the IEC standard) on BC bifacial modules at an installation angle of 30 degrees (while the conventional test is usually carried out at 15 degrees). After these tests, no microcracks were found in the BC modules.

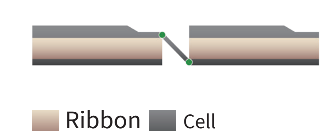
BC module

The risk of microcracks is low; the stress at the edge of the cell is **26Mpa**



Conventional module

The risk of microcracks is higher; the stress at the edge of the cell is **50Mpa**

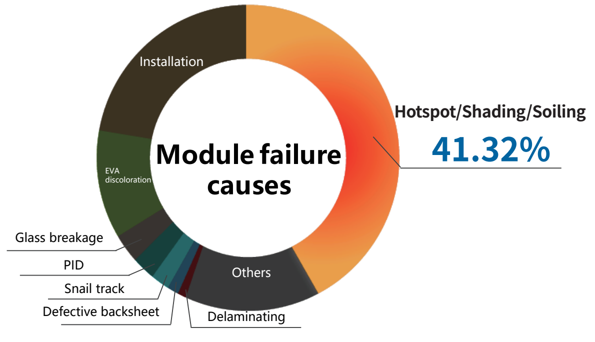


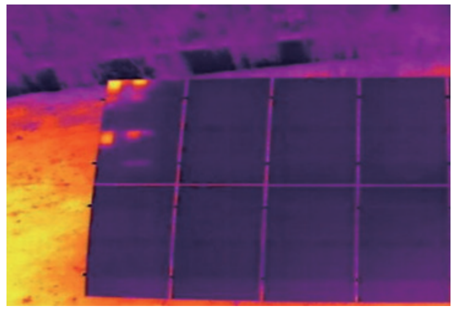
4.3.2 Good Prevent localized overheating resistance

By conducting systematic O&M data analysis on the diversified application scenarios of nearly 10 GW-level PV power stations (which include typical scenarios like deserts, mountainous areas, floating on water surfaces, water surface pile foundations, ground installations as well as industrial and commercial rooftops), it has been demonstrated that module shading and hot spot effect have already emerged as the core technical bottlenecks that constrain the safe operation of power stations and the enhancement of power generation efficiency. The data reveals that approximately 49.7% of the module failure cases stem from the problem of shadow shading. Moreover, the compound performance degradation composed of shading, hot spot and contamination has a superimposed negative impact on the reliability of PV systems.

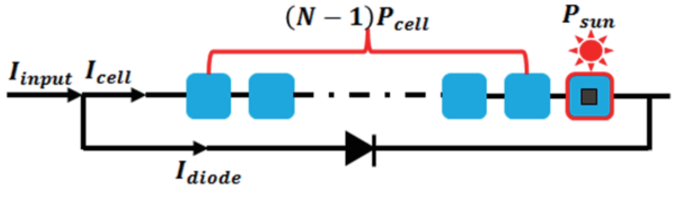
Analyzed from the dimension of safety risks, the hot spot effect, which serves as a crucial inducement in the accident chain of PV system fires, has an accident traceability proportion reaching 34.6% [10]. Research on the failure mechanism shows that the non-uniform shadow distribution on the surface of modules, which is caused by dust deposition, vegetation shading, building shading, bird droppings and other foreign substances, will lead to an abnormal increase in the local temperature of the cells to the critical range of 160°C-180°C, and then trigger the risks of thermal degradation of materials and insulation failure.

Typical case verification indicates that in a 20 MW ground-mounted power station, as many as 8,213 abnormal hot spot points were detected during in-depth inspections (test standard: EL ⩾ 3% power loss). This is equivalent to having 410.6 potential thermal fault points for each megawatt of installed capacity.





The essence of shading hot spots is that after the cells are shaded, they are unable to generate electricity and thus change from power sources to resistors. As a result, the power generation of the modules is consumed by the internally shaded cells, generating a large amount of heat and causing the actual temperature of the modules to reach above 100°C.



In order to reduce the impact brought by hot spots, conventional modules adopt three external bypass diodes in the module design to isolate the hot spot strings. However, as the module formats become larger and larger, the heat generated by the bypassed strings remains very high, which easily leads to module failure and even the fire risk.

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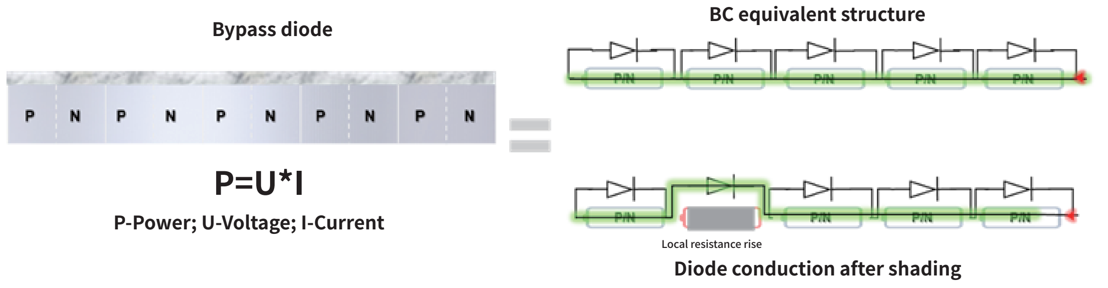
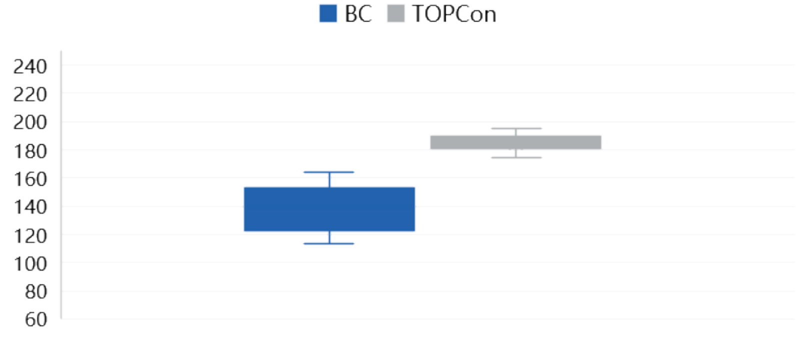
BC modules take advantage of the cell-level bypass diode function, which is realized by means of the microcircuit design of BC cells and the laser patterning technology. In the event that a cell is shaded, it is capable of bypassing the individual cell, thereby substantially reducing the energy consumption of the shaded cell and further lowering the localized overheating temperature to a great extent. The high-temperature suppression function offers a dependable safeguard for the safe power generation.

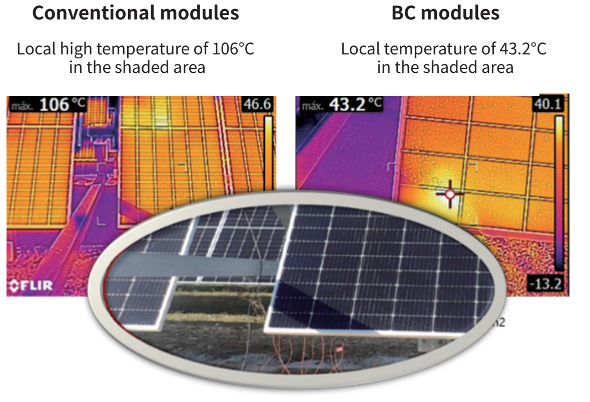


As indicated by the test report from the authoritative third-party organization TÜV Rheinland, when a single cell is completely shaded for one hour, the localized overheating temperature of the BC cell is noticeably lower, dropping by over 30% compared to that of the TOPCon cell. This effectively reduces the risk of the localized overheating effect, extends the lifespan of the modules, and bolsters the reliability of the PV system.

Comparison of results of local high temperature tests by TÜV Rheinland



Furthermore, during the monitoring of actual projects, BC modules have also exhibited the feature of having a low localized overheating temperature. Specifically, the localized overheating temperature of BC modules is 63°C lower than that of conventional modules, and it is below the long-term operational safety temperature of the encapsulating materials. As a result, the encapsulating materials will not become ineffective due to the continuous emergence of localized overheating.



4.4 More appealing appearance

BC modules employ the innovative back contact technology, which thoroughly gets rid of the visual interference brought about by the front-side metal busbars of traditional PV modules, thus showcasing an exquisitely pure dark mirror effect. In contrast to conventional modules, there are no busbars, fingers, or ribbons on its surface to cause any shading. The overall appearance is both flat and smooth, and the color is uniformly consistent, embodying the minimalist aesthetics characteristic of high-end technological products. This design not only significantly enhances the visual quality of the module under natural light but also allows it to seamlessly integrate into various architectural scenarios, whether it is modern residential roofs, commercial facades, or public buildings with strict aesthetic requirements. The BC module can provide an elegant visual effect, serving as a photovoltaic solution that combines functionality and aesthetics

BC module

No busbars, fingers, or ribbons on its surface
The overall appearance is flat and smooth, with uniform color.

Conventional module

There is occlusion of busbars, fingers, or ribbons on its surface
The overall appearance is not flat and smooth, and the color is not uniform.

Chapter 5
Application Value of BC Modules

Relying on their remarkable edge in conversion efficiency, BC modules can notably cut down the Balance of System (BOS) costs, excluding those of the modules, during the actual construction of PV power stations in comparison to the TOPCon technology. The reduction rate can surpass 6% of the total cost of the power station (Not including module). Simultaneously, by virtue of its advanced photoelectric conversion features, this technology has exhibited a more outstanding power generation capacity per kilowatt across diverse geographical environments, climate conditions and varied application scenarios all over the globe. Empirical research has demonstrated that the power generation gain over its entire life cycle remains steadily within the range of 1% to 2%. In practical operation scenarios, when compounded with environmental factors like dust accumulation, vegetation shading and shadow shading among modules, the power generation gain can even ascend to over 7%. By integrating the dual advantages of system cost optimization and power generation performance improvement, the BC technology can effectively lower the levelized cost of energy (LCOE), thus offering a technical safeguard for the economic performance throughout the entire life cycle of PV power stations.

5.1 BC products contributing to a lower levelized cost of energy (LCOE)

With reference to the Specification for Photovoltaic Power Generation System Performance (NB/T 10394-2020), LCOE, which stands for levelized cost of energy, represents the power generation cost obtained through the process of leveling all costs and electricity generation throughout the entire life cycle of a PV power station. In other words, it is calculated as the present value of costs within the life cycle divided by the present value of electricity generation within the life cycle. LCOE acts as the foremost metric for evaluating technological advancement. Product technologies boasting a more favorable LCOE are more prone to being rapidly embraced by the market and undergoing technological iterations smoothly.

The calculation formula for LCOE is as follows:

$$LCOE = \frac{\left[I_0 - \sum_{n=1}^{N}\frac{I_t}{(1+i)^n} - \frac{V_R}{(1+i)^N} + \sum_{n=1}^{N}\frac{M_n}{(1+i)^n}\right]}{\sum_{n=1}^{N}\frac{Y_n}{(1+i)^n}}$$

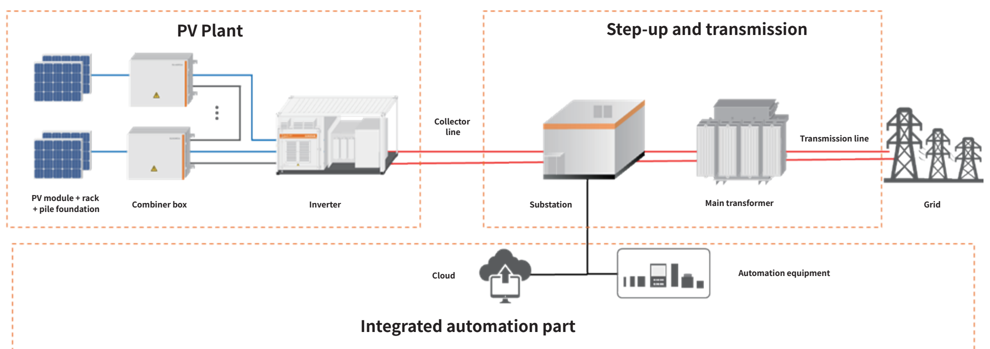
The core factors influencing LCOE are the initial construction cost, the O&M cost throughout the life cycle, and the power generation over the entire life cycle.

5.1.1 Contribution of BC modules to the reduction of power station construction costs

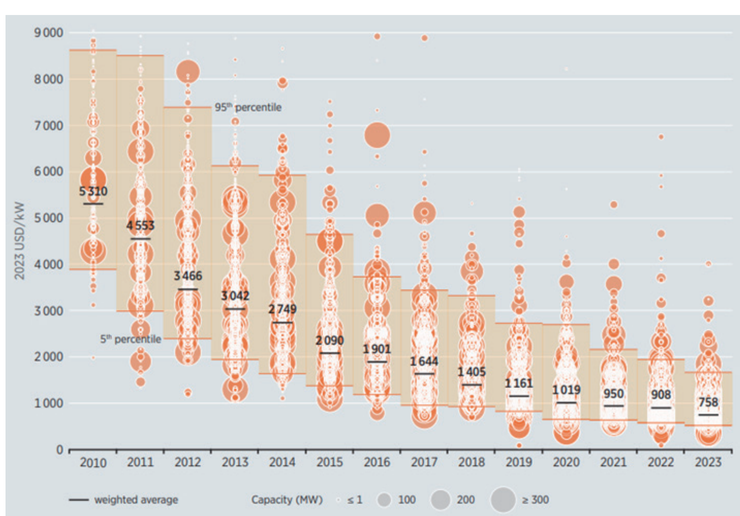
In the cost composition of PV power station systems, the BOS (Balance of System) cost occupies a central position. The BOS cost can be divided into two major systems, namely dynamic BOS and fixed BOS, through technical deconstruction.

The dynamic BOS cost primarily encompasses the structure system (PV racks and pile foundation works), the electrical system (DC cables, inverters, box-type transformers, and low-voltage AC cables), as well as the space efficiency cost (land rental expenses during the construction period). This portion of the cost is directly influenced by parameters like the power density and conversion efficiency of modules. Significantly, there is ample room for cost reduction through technological iterations.

In the fixed BOS (Balance of System) cost system, the infrastructure including step-up substation construction, collector lines, outgoing transmission projects, and energy storage facilities is involved. The total investment scale of these aspects has a weak correlation with the selection of modules. Instead, it is mainly constrained by the overall scale of the project as well as the grid connection requirements.



Benefiting from the higher efficiency advantage of BC modules, a greater installed capacity can be realized compared to TOPCon modules on the same land area. Specifically, the installed capacity can be boosted by over 6%. Moreover, when BC modules are used to replace those of the same module type, the BOS (Balance of System) cost per watt can be decreased by 6%. Judging from the utility construction costs worldwide in 2023 (the values are taken from RENEWABLE POWER GENERATION COSTS IN 2023 released by IRENA in 2024), the costs excluding module costs range from 0.24$/W to 1.10$/W, and the average global non-module construction cost is 0.55$/W.



Based on the median non-module cost of ¥3.5/W in global PV construction projects, the application of BC technology can reduce non-module construction costs by an average of ¥0.18/W (DC capacity basis). This translates to higher return on investment for PV power stations investments.

A real - design comparison was conducted by selecting some typical global scenario projects. The investment costs of BC technology modules and TOPCon modules were compared. Using BC technology modules can reduce the BOS cost of power stations by 0.09 - 0.22 yuan per watt. The specific details are shown in the following table:

Configuration of schemes for measurement methods of different capacities on the same land area

Scenario		Desert, gobi, and barren land		Mountainous terrain scenario		Tracking scenario		Floating scenario	
Project location	Unit	Qinghai		Hubei		Brazil		Thailand	
Scenario area	mu	1562		1414		1989		1237	
Product type	/	TOPCon/625	BC/660	TOPCon/625	BC/660	TOPCon/625	BC/660	TOPCon/625	BC/660
DC capacity	MW	100.4	106.2	133.2	140.6	122.7	129.6	133.0	140.5
Variable BOS	Cent/W	Base	-0.40	Base	-0.38	Base	-1.18	Base	-0.70
Fixed BOS	Cent/W	Base	-1.23	Base	-0.92	Base	-1.81	Base	-1.14
Comprehensive BOS	Cent/W	Base	-1.62	Base	-1.30	Base	-3.00	Base	-1.84

5.1.2 Increase in electricity generation revenue of BC modules

Under the comprehensive influence of parameters like irradiance, environmental and climatic conditions (including ambient temperature, irradiance, and wind speed), as well as ground reflectance in various geographical regions across the globe, the electricity generation per unit installed capacity of BC PV modules and those of products based on the TOPCon technical route demonstrate distinct characteristics. In this research, the PVsyst PV system simulation software is employed to build a refined simulation model. Subsequently, four typical application scenarios, including the high-latitude cold temperate zone, the mid-latitude temperate zone, the low-latitude subtropical zone, and the high-altitude strong irradiation area, are chosen for the purpose of carrying out a comparative analysis. Through a systematic assessment of the differences in the influence exerted by core parameters like the temperature coefficient, bifaciality, and low-light response characteristics of modules on power generation performance, the quantification and comparison of the power generation revenues over the entire life cycle

BC electricity generation gain in typical environment

Scenario	Base item	Desert, gobi, and barren land	Mountainous terrain scenario	Tracking scenario	Floating scenario
Project location		Qinghai	Hubei	Brazil	Thailand
Product type	TOPCon-625W	BC-660W			
Rack type	/	Fixed rack/2P	Fixed short rack/2P	Tracking rack/1P	Floating body rack/2L
Electricity generation gain over the entire life cycle	BL	7.14%	7.69%	7.57%	7.91%

Considering various climate conditions worldwide, the power generation capacity per watt of BC product power stations throughout the entire life cycle is 1% to 2% higher than that of TOPCon. (It should be noted that as some characteristics of BC technology cannot be fully manifested in the simulation at present, the actual power generation gain during the operation of real projects is actually higher than this figure.) Given that BC products boast higher efficiency and can enable a 6% increase in installed capacity for the same project, the overall use of BC products in power stations can bring about a 7% to 8% power generation gain, which significantly enhances the investment value of the projects.

5.1.3 Value of BC modules in reducing LCOE

Drawing on the empirical data analysis of the principal global photovoltaic markets, BC modules have manifested remarkable technological advantages in the optimization of the levelized cost of energy (LCOE) throughout the entire life cycle. Based on multi-scenario modeling and calculations, BC modules can bring about a cost reduction amplitude of 4% to 5% in the LCOE when compared with mainstream technical solutions. Specifically, the higher the construction and O&M costs of the power station as well as the average operating temperature during its operation are, the greater the reduction proportion of LCOE will be. This fully validates its advantages in technological adaptability.

Comparison item	Base item	Delingha desert, gobi, and barren land	Hubei mountainous region	Brazilian grassland	Thailand fresh water
		Fixed rack scenario	Fixed rack scenario	Flat single-axis rack scenario	Floating rack scenario
Product type	TOPCon	BC			
Power-W	625	660			
LCOE (%)	BL	-5.55%	-5.86%	-6.36%	-6.28%
Equal LCOE product value (cent/W)	BL	2.31	2.08	4.60	3.12

Under the same LCOE, Bc products have a value of 2.06~4.67 cents per watt in major global photovoltaic markets,which is far higher than the current price difference between mainstream BC modules and TOPCon modules; the widespread application of Bc products can inject new vitality into the reduction of global LCOE.

5.2 BC modules more prominent in value shaded environments

The value of BC modules will be further magnified in shaded environments. Take, for instance, the situations where wind and PV power are combined in the same site, in complex mountainous terrains or on rooftops. Since these environments are affected by certain shading factors, the application of BC modules enables a more efficient utilization of land area and concurrently boosts the electricity generation even when there is shading, thereby improving the stability of the investment incomes of power stations in a better way.

Scenarios with Coexistence of Wind and Solar Power:

Scenario Characteristics: In co-located wind and solar projects, the high elevation of wind turbines results in extensive shadow coverage. During solar design, there is often a desire to avoid turbine shadow areas. However, completely avoiding these zones leads to a significant reduction in installed capacity and inefficient resource utilization. On the other hand, partial deployment of module in shaded areas may reduce power generation and introduce reliability risks, jeopardizing return on investment (ROI).

BC Product Advantages: BC modules, with their superior power generation performance under shading conditions, can be installed in partial turbine shadow zones. Leveraging their shading resistance, they enhance land utilization in wind farms while ensuring power output and reliability. Combined with BC modules' high efficiency, this approach significantly increases installed capacity, optimizes resource utilization, and improves ROI. For offshore scenarios with high seabed usage fees and short construction windows, this advantage further boosts ROI.

Mountainous Scenarios:

Scenario Characteristics: Complex terrain and dense vegetation make it challenging to avoid front-to-back row shading during design and construction. Vegetation growth during operation further impacts power generation and safety. To maintain efficiency, mountainous projects require higher operational and maintenance (O&M) costs.

BC Product Advantages: With their high efficiency, BC modules enable flexible layout designs to avoid shading or widen row spacing, reducing shading-related construction requirements. This maximizes land use efficiency and increases power output per unit area. **BC modules exhibit 30% lower hot spot temperatures under shading compared to conventional products, ensuring long-term reliability, reduced fire risks, and lower O&M costs while minimizing energy loss.**

Rooftop Scenarios:

Scenario Characteristics: Limited space, dynamic shading environments (e.g., nearby structures or vegetation), and integration with living/industrial spaces demand higher aesthetic standards and operational safety. Additionally, low tilt angles on rooftops lead to dust accumulation at panel edges, reducing efficiency and increasing heat.

BC Product Advantages: BC modules' front-side gridless design offers an aesthetically clean appearance ideal for building-integrated photovoltaics (BIPV). Their shading resistance and reduced hot spot effects significantly improve rooftop system output and reliability, enabling higher returns with lower risks. The design also mitigates edge dust accumulation issues, further enhancing long-term performance.

5.3 Demonstration performance in multiple climate zones/scenarios

Since the mass production of BC technology modules, Aiko and LONGi have collaborated with third parties and customers to establish over 30 demonstration plants worldwide for outdoor power generation verification. These projects cover diverse application scenarios, including utility and distribution systems, varying climatic conditions, and different ground albedo. In all scenarios, BC technology has demonstrated excellent power generation performance. Below are some data from the demonstration projects:

Distribution Plants Demonstration Performance under Non-shading Condition

Category	Demonstration power station	Country	Scenario	Shading type	Empirical data -base TOPCon	Explanation for high power generation reasons
Non-shading distribution plants	Nanjing, Jiangsu Demonstration Plant	China	Flat Roof	No	2.76%	BC modules possess a more favorable temperature coefficient and a better IAM.
	Xianyang, Shanxi Demonstration Plant	China	Color steel tile		2.57%	
	Madrid Demonstration Plant	Spain	roof		1.93%	
	Xi' an, Shaanxi Demonstration Plant	China	Roof		1.21%	

Distribution Plants Demonstration Performance under Shading Condition

Category	Demonstration power station	Country	Scenario	Shading type	Empirical data -base TOPCon	Explanation for high power generation reasons
Shading distribution plants	Meizhou, Guangdong Demonstration Plant	China	Residential Roof	Roof building shading	4.01%	BC modules possess a more favorable temperature coefficient , anti-shading performance, and a better IAM.
	Quanzhou, Fujian Demonstration Plant	China	Flat Roof	Roof building shading	6.42%	
	Huaian, Jiangsu Demonstration Plant	China	Residential Roof	Roof building shading	6.95%	
	Yinchuan, Ningxia Demonstration Plant	China	Flat Roof	Module string shading	5.00%	
	Ishikawa Demonstaration Plant	Japan	Parking PV Roof	Partial shading	10.74%	

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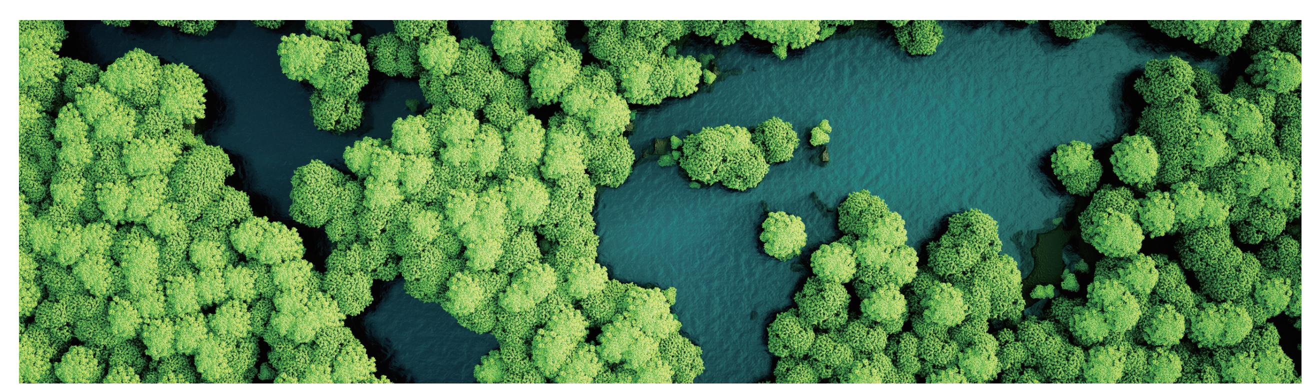
Utility Plants Demonstration Performance under Non-shading Condition

Category	Demonstration power station	Country	Scenario	Shading type	Empirical data -base TOPCon	Explanation for high power generation reasons
Non-shading Utility plants	Tunchang, Hainan Demonstration Plant	China	Mountain	No	3.01%	BC modules possess a more favorable temperature coefficient, a better IAM and a better operation temperature.
	Zhanjiang,Guangdong Demonstration Plant	China	Dirt Ground		1.95%	
	Binggou, Ningxia Demonstration Plant	China	Sand		1.39%	
	CPVT Yantai, Shandong Demonstration Plant	China	Sea		3.22%	
	Taizhou, Jiangsu Demonstration Plant	China	Grass		1.51%	

Utility Plants Plants Demonstration Performance under Shading Condition

Category	Demonstration power station	Country	Scenario	Shading type	Empirical data -base TOPCon	Explanation for high power generation reasons
Shading Utility plants	CGC Sanya Demonstration Plant	China	High temperature and humidity	Partial shading	32.62%	BC modules possess a more favorable anti-shading performance.
	CGC Sanya Demonstration Plant	China	High temperature and humidity	Pillar shading	11.34%	
	Binggou, Ningxia Demonstration Plant	China	Desert	Pillar shading	33.4%	
	Huizhou, Guangdong Demonstration Plant	China	Floating	Leaves and bird droppings shading	3.96%	



Chapter 6
BC Ecological Construction

6.1 Policy and standard recommendations

In order to boost the high-quality development of the PV industry, a host of policy documents have been rolled out by national ministries and commissions as well as different provinces. These policies have laid a solid foundation for the research, development and industrialization of high-efficiency cell technologies with BC taking the lead, thus facilitating the innovation and upgrading of the entire industrial chain.

On November 20, 2024, the Ministry of Industry and Information Technology of China issued the Specifications for the Photovoltaic Manufacture Industry (2024 Edition). By raising the technical indicator threshold, strengthening the requirements for green manufacturing, and optimizing the production capacity layout, it significantly benefits the market promotion and technological iteration of high-efficiency PV modules. The policy has clearly heightened the efficiency threshold for new projects. Specifically, it demands that the average photoelectric conversion efficiency of newly constructed N-type mono-crystalline silicon solar cells shall reach no less than 26%. Moreover, it has put forward stricter efficiency standards for existing projects, thereby creating development opportunities for advanced technical routes that possess high conversion efficiency and technological innovation capabilities.

At the local level, on November 15, 2024, the Shanghai Municipal Development and Reform Commission released the Work Plan for the Competitive Allocation of Offshore Photovoltaic Projects with Co-located Wind and PV Power in 2024. Under this plan, seven offshore PV projects featuring co-located wind and PV power were scheduled to undergo competitive allocation. In accordance with the scoring regulations, additional points can be obtained by using high-efficiency modules and inverters. In particular, modules with a conversion efficiency of 24% are eligible to score full marks. This shows that Shanghai attaches great importance to high-efficiency modules in offshore PV projects, which has provides greater market opportunities for high-efficiency PV technologies like BC modules.

Two months later, the "Top Runner Program" in Shaanxi Province, China was released. On January 9, 2025, the Shaanxi Provincial Development and Reform Commission issued the Notice on Carrying out the Work Related to the Development and Construction of Wind Power and Photovoltaic Power Generation Projects in Shaanxi Province in 2025, clearly stating that 10 GW of new wind power and photovoltaic guaranteed-access indicators would be added, and a 2 GW photovoltaic "Top Runner Program" would be implemented, requiring the module conversion efficiency to reach above 24.2%. This measure aims to effectively raise the product access threshold by restricting high-efficiency module products, guide the industry to pursue new technologies with higher efficiency and lower costs, and set a benchmark for the high-quality development of the photovoltaic industry.

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On February 8, 2025, the Sichuan Provincial Economy and Information Department and seven other departments jointly issued the Notice on Several Measures to Support the Sustainable and Healthy Development of the Photovoltaic Manufacturing Industry. It clearly stated that technological innovation should be strengthened, with a focus on carrying out systematic industrial chain research and pilot test verification on the key core technologies of perovskite, cadmium telluride, and BCBC cells, aiming to help more photovoltaic manufacturing enterprises meet the latest national regulatory requirements. This initiative will provide a solid R&D foundation and a cooperation platform for the innovation and breakthrough of BC module technology, and accelerate its industrialization process. Meanwhile, this policy promotes more photovoltaic manufacturing enterprises to meet the latest national regulatory requirements and become industry benchmarks. It not only helps to improve the overall quality and production standards of BC modules but also enhances their competitiveness in the market, further facilitating the wide application and popularization of BC modules.

6.2 Supply chain collaborative innovation

Leading enterprises in BC technology have been consistently committed to technological innovation. They ceaselessly strive to explore the boundaries of technology while maintaining an open and innovative mindset. Actively forging open collaborations with enterprises across the industrial chain, they focus on collaborative innovation and value sharing .Through continuous efforts in refining product production processes, upgrading or developing new equipment and materials, and so on, these enterprises have managed to attain the objective of reducing costs and enhancing efficiency for their products. Ultimately, they have successfully achieved large-scale mass production of their products.

The continuous innovation in equipment and materials provides robust support for the industrial development of BC technology.

6.2.1 Laser patterning technology

The process preparation of traditional BC cells requires multiple steps such as glue coating, exposure, development, etching, and cleaning to be completed, resulting in high production costs and a low yield. Through the collaborative innovation of laser equipment enterprises, the laser patterning technology has been introduced into the preparation of BC cells for the first time, significantly reducing the production cost and improving the yield, and accelerating the marketization process of BC technology.

In the field of laser technology, many equipment manufacturers are accelerating the implementation of BC technology. DR Laser has launched a dedicated laser micro-etching equipment for BC, which meets the requirements of mass production lines and replaces the traditional photolithography process. Hymson has achieved the patterning production of high-efficiency back contact cells (BC) based on the laser mask etching technology. The BC laser film cutting equipment has passed the mass - production verification.

6.2.2 Performance improvement of PV insulating glue

As a core material for PV BC cells, PV insulating glue plays a role in insulation and protection in BC cells, ensuring good contact between electrodes and wafers, while also preventing current leakage and short circuits. It is required to possess excellent insulation properties, good bonding strength, and high temperature resistance. Leading enterprises in BC technology, in collaboration with material enterprises, have successfully developed insulating glue materials with comprehensive performance that meets the requirements through multiple process improvements and product performance tests, thus comprehensively enhancing the reliability of products with BC technology. Kuangshun has produced high-reliability insulating glue specifically for BC, which is suitable for high-temperature process environments. First has optimized the formula of low-stress insulating glue and passed the industry standard certification.

6.2.3 String soldering equipment upgrade

Due to the structural characteristics of the back contact in BC cells, it is necessary to avoid the shading of the frontside electrodes and ensure the soldering accuracy on the backside. Traditional string soldering equipment is faced with the challenges of a high fragmentation rate and insufficient alignment accuracy. Thanks to the technological upgrades and process adaptations by string soldering equipment manufacturers, the soldering yield in the mass production of BC cells has been significantly improved, further facilitating the large-scale implementation of this technology.

Wuxi Autowell Technology Co., Ltd. has already introduced a high-precision multi-spot stringer machine that is compatible with BC cells. Its equipment has been incorporated into the mass production lines of leading enterprises in the BC technology field, such as LONGi and Aiko. Wuxi Lead Intelligent Equipment Co., Ltd., by leveraging its advantages in automation technology, has developed a dedicated BC string soldering module. This module employs a flexible pressing and visual alignment correction system, which can well adapt to the trend of thinner N-type BC cells. Jinchen Corp has realized efficient interconnection by integrating laser soldering and electromagnetic drive technologies.

6.2.4 Coating equipment optimization

The preparation of the tunnel oxide layer and the doped polysilicon layer of BC cells relies on coating equipment, and domestic manufacturers dominate the technology supply. The LPCVD equipment developed by LAPLACE serves as the core process equipment for fabricating the new high-efficiency PV cell BCBC, and it has already been put into use in the production line. The coating equipment of Shenzhen S.C is suitable for mass production with passivated contact structures. The ALD technology of Leadmicro Nano can improve the passivation performance of N-type BC cells.

6.3 BC module manufacturing enterprises

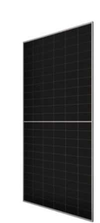
6.3.1 LONGi

On May 7, 2024, LONGi made a significant announcement in Madrid, Spain, unveiling a new record for the efficiency of crystalline silicon solar cells and a brand-new generation of high-value module product, Hi-MO 9. The Hi-MO 9 module is a new-generation BC product created by LONGi relying on the highly efficient HPBC 2.0 cell technology. It centers on meeting the demands of utility PV stations for high power generation performance and product reliability throughout the whole life cycle, thus offering users the product solution with the best power generation performance over the entire life cycle. The Hi-MO 9 module of LONGi incorporates multiple advanced technologies and boasts the core product advantages of higher power generation capacity, lower BOS (Balance of System) costs and higher reliability.

On October 11, 2024, LONGi released the Hi-MO X10 module to the global distributed market. The Hi-MO X10 module is based on the HPBC 2.0 high-efficiency BC cell technology and integrates features from LONGi's previous distributed products. It offers enhanced flexibility in module size, an all-black aesthetic, and dust-resistant functionality, providing globally distributed customers with product options tailored to various application scenarios.

On April 11, 2025, LONGi Green Energy launched the upgraded Hi-MO 9 module and a new efficiency record for monocrystalline silicon cells in Wuhu, Anhui. The company detailed the comprehensive adoption of advanced technologies in the HPBC 2.0 cells, including full-area passivation of half-cut cells, 0BB (zero busbar) technology, sub-micron texturing, and optimized grid lines. These innovations have increased the power output of the Hi-MO 9 module to 670W and raised the module efficiency to 24.8%. Additionally, with the full-scale production of 0BB technology and upgraded graphical techniques, the bifaciality ratio of the Hi-MO 9 module has been enhanced to 75% (with an optional unlock for an 80% bifaciality ratio), further boosting the module's competitiveness across all application scenarios.

Main BC products of LONGi:

Corporate	Main series	Subseries	Model	Wafer size/mm	Model size/mm	Power range/W	Module efficiency
	**Hi-MO 9**	/	66	182.2*210	2382*1134	655~670	24.80%
	**Hi-MO X10**	Scientist	54	182.2*192	1800*1134	495~505	24.70%
			72	182.2*192	2382*1134	655~670	24.80%
		Explorer	54	182.2*192	1800*1134	475~490	24.10%
			72	182.2*192	2382*1134	630~650	24.10%
		Guardian	72	182.2*192	2382*1134	640~670	24.80%

6.3.2 Aiko

In 2021, Aiko was the first to release the N-type ABC cell. At that time, the ABC cell demonstrated its natural high-efficiency advantages brought by the frontside busbar-free structure and bipolar passivation, with an efficiency of 26.5%, leading the industry. In 2022, the N-type ABC module was launched with an efficiency of 23.5%. After overcoming the challenges of yield and cost reduction, Aiko achieved the large-scale commercial production of the N-type BC technology in 2023. Aiko has adopted its own patented silver-free metallization coating technology in ABC cells. By replacing silver electrodes with pure copper, it has achieved fully silver-free mass production, reduced silver consumption, put the environmental protection concept into practice. Meanwhile, it has enhanced the toughness and strength of the cells, reduced the risk of microcracks, effectively cut down the silver cost for cells, ensured an abundant supply of raw materials, and provided strong support for the sustainable development of the PV industry.

Aiko currently has four major series, namely the "Black Hole", "Star", "Comet", and "Nebula" series.

The "Black Hole" series mainly focuses on the residential market and is adapted to the differentiated needs at home and abroad. The "Comet" series is customized specifically for industrial and commercial scenarios, with enhanced safety and better adaptability to various scenarios. The "Nebula" series breaks through the load-bearing capacity limitations of building roofs and expands the range of available roof resources. The "Star" series, which includes the "Polaris" and the "Sirius", covers complex ground-mounted power station scenarios such as those in mountainous areas, deserts and offshore.

The main BC products of Aiko are as follows:

Corporate	Main series	Model	Wafer size/mm	Model size/mm	Power range/W	Module efficiency
 N-type ABC series	"Black Hole" series	78	182.2*210	2465*1303	770~785	24.4%
		78	182.2*184	2465*1134	655~680	24.3%
		54	182.2*187.75	1757*1134	440~485	24.3%
	"Star" serles	66	182.2*210	2382*1134	635~670	24.8%
		72	182.2*192.5	2382*1134	635~670	24.8%
	"Comet" series	72	182.2*192.5	2382*1134	640~670	24.8%
	"Nebula" series	54	182.2*187.75	1762*1134	435~450	22.5%
 N-type ABC full screen series	"Black Hole"-full-screen series	54	182.2*192.5	1762*1134	460~500	25.0%

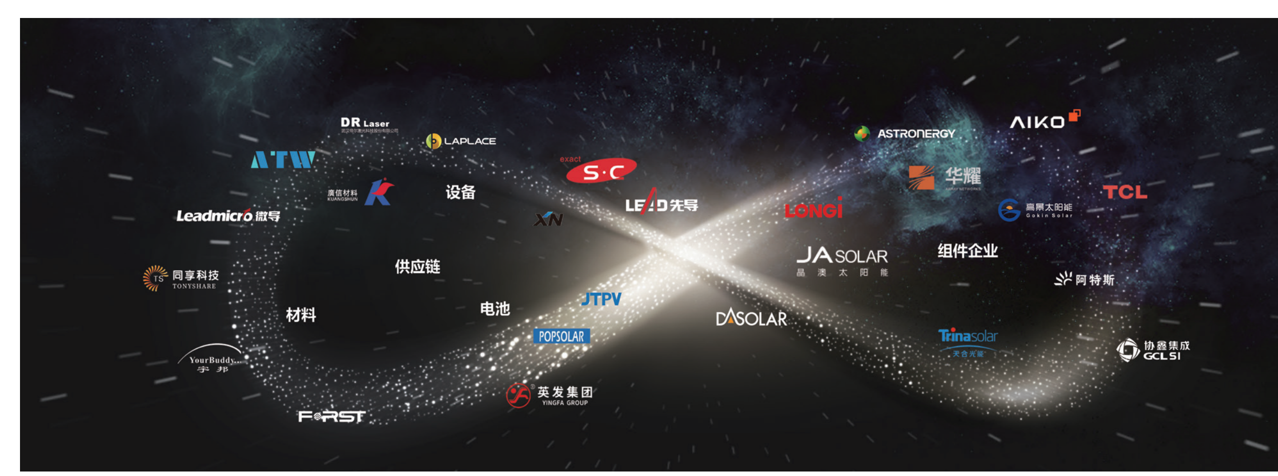
6.3.3-TCL

As early as 2004, Maxeon launched the first-generation commercial IBC solar cells based on the diffusion process, with a conversion efficiency exceeding 20%. Since 2015, the company has initiated the research and development of the TBC structure. From 2023 to 2024, the company released the seventh-generation (Gen 7) technology, and has currently achieved a module efficiency of 24.7%. Maxeon plans to launch the eighth-generation technology Gen 8 (or Max 8 for short) in 2025. It will adopt a new architecture and a larger wafer size, with the goal of increasing the module efficiency to over 25%.

Maxeon has adopted a design with a solid metal substrate, which effectively mitigates metal stress and enhances the durability of its modules. This sets it apart from traditional cells like mono-crystalline PERC, TOPCon, and HJT that primarily rely on the design of metal ribbon. The metal ribbons in traditional modules may bend due to temperature changes, resulting in a decline in their performance. According to the results of third-party tests, Maxeon's modules perform better than the top TOPCon modules on the market in the damp heat aging test.

6.3.4 Others

In addition to LONGi, Aiko, TCL and other enterprises that have fully shifted the focus of their future development to BC technology, the mainstream module manufacturers in the industry have successively released their BC module products since 2024, proving to the market that they will gradually focus on BC technology in the future. In 2024, enterprises such as GCL, Chint, Trina Solar, DAS Solar, and Huayao showcased their BC modules at various exhibitions. In 2025, Tongwei, JA Solar, and Gokin also made high-profile releases of their BC modules. Although there are differences between TBC and HBC among various companies in the BC technical route, currently, the investment in BC technology has already become the main investment direction for photovoltaic manufacturing enterprises. BC, as a mainstream technology, has begun to take shape on the manufacturing side.



Chapter 7
Future Prospects

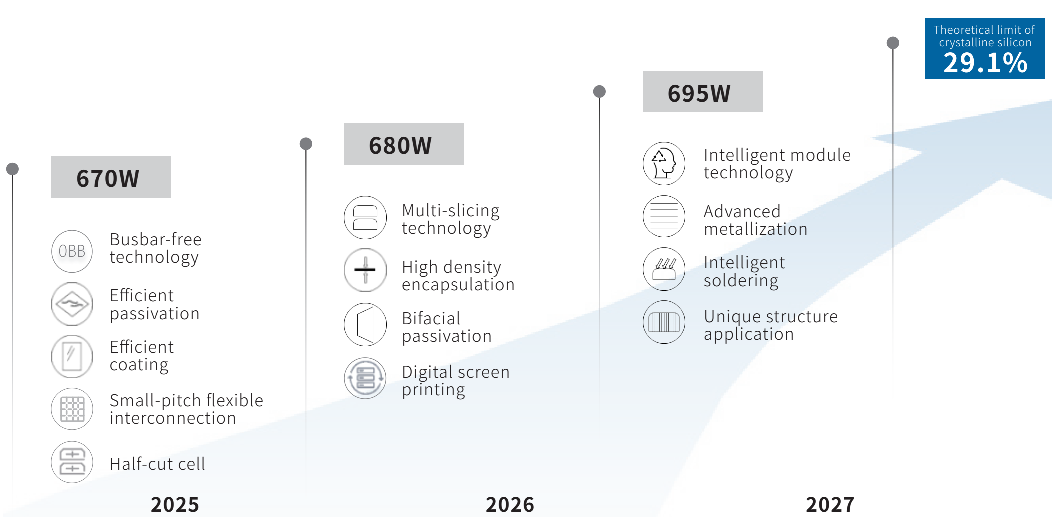
The evolution of photovoltaic (PV) technology has always revolved around the core goals of "higher conversion efficiency, lower levelized cost of electricity (LCOE), and broader application scenarios." Future cost reduction in the PV industry will primarily stem from improvements in cell and module efficiency. Based on a cell conversion efficiency of 27%, each additional percentage point of efficiency gain can save approximately 4% in costs for downstream power stations and reduce the LCOE by over 3%.

7.1 BC Technology Evolution Direction

The current mass production efficiency of BC cells is around 27%, with module efficiency at approximately 24.4%. This already significantly outperforms the bifacial contact PV technology route. However, there remains a gap of about 2% between the current efficiency of BC technology and its theoretical limit. With continuous optimization of BC cell technology, over the next 3 to 5 years, BC cell efficiency is expected to reach around 28.5%, with overall module efficiency exceeding 26%. This will ensure the sustained technological leadership of BC modules.

In terms of improving the efficiency of cell technology, BC cells will continue to make efforts in aspects such as light management, bipolar recombination passivation, and new and advanced metallization in the next few years, steadily reducing electrical losses and gradually increasing their photoelectric conversion efficiency.

In terms of improving the efficiency of modules, it will increase the overall encapsulation proportion of cells within a limited area through the realization of mass production of multi-slicing and high-density encapsulation technologies. Moreover, through breakthroughs in technologies such as intelligent soldering and intelligent module technologies, it will significantly reduce the losses caused by soldering and circuit mismatches, further enhancing the efficiency of modules.



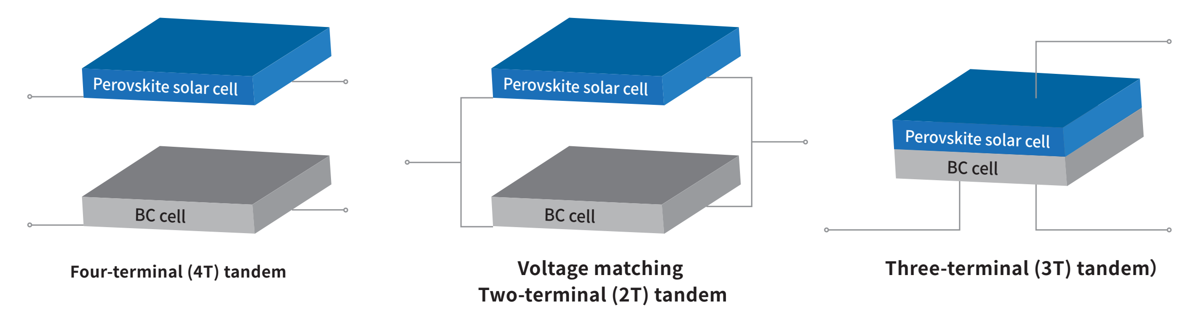
7.2 Iteration direction of tandem technology (perovskite/BC tandem)

Currently, the crystalline silicon solar cell technology has already approached the theoretical efficiency limit of 29.4%. In contrast, the perovskite/crystalline silicon tandem technology has raised the theoretical efficiency ceiling to over 45%. Such a significant leap in efficiency will trigger a reconstruction of the value chain in the industry. Nevertheless, in the era of silicon/perovskite tandem, BC still maintains strong momentum.

Four-terminal or voltage-matching two-terminal tandem solar cells don't need current matching. Perovskite top cells enjoy a broader selection scope and exhibit superior stability, thus being considered as the silicon/perovskite tandem solar cells that are most likely to take the lead in entering the market. On the other hand, BC cells possess high efficiency and are free of frontside busbars. During the lamination process, they can inflict less damage on soft lattice perovskite solar cells, which makes them an outstanding option for four-terminal or voltage-matching two-terminal tandem solar cells.

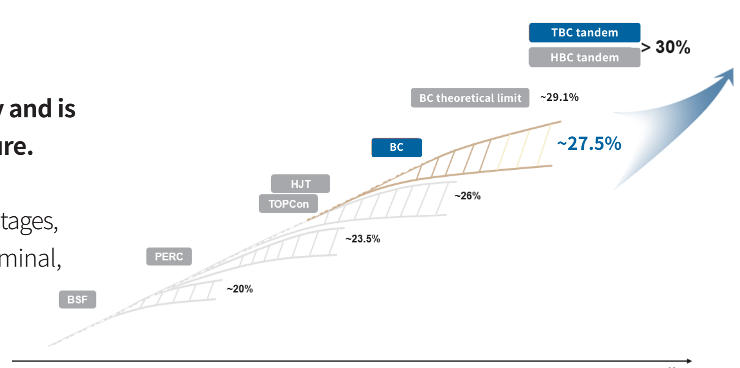
The tandem solar cells with a series connection based on BC crystalline silicon bottom cells are called three-terminal tandem solar cells because they have three electrodes led out. The biggest advantage of three-terminal tandem solar cells is that there is no need for strict current matching between the top cell and the bottom cell. Perovskite solar cells can achieve relatively high cell efficiency within a relatively wide range of band gaps. More importantly, three-terminal tandem solar cells can automatically adjust the current distribution between the top and bottom cells under different illumination conditions. They can be regarded as a kind of smart tandem solar cells (Smart tandem). Theoretical calculations show that three-terminal tandem solar cells may possess better actual outdoor power generation capabilities than two-terminal and four-terminal ones. Therefore, three-terminal tandem solar cells, which combine the respective advantages of two-terminal and four-terminal ones, may become the ultimate solution for tandem solar cell technology.

In addition, the technologies on BC cells (such as passivation contact structures) can also be directly transferred to two-terminal tandem solar cells. Therefore, BC cell technology can be applied to almost all types of silicon/perovskite tandem solar cells.



BC technology leads the current cell technology and is also a cell technology oriented towards the future.

In the future tandem era, relying on its structural advantages, BC cells will still shine brightly in the fields of three-terminal, four-terminal and other tandem solar cells. BC will be a long-term winner.



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