ASTRONERGY

Future, with Numerous ASTRO

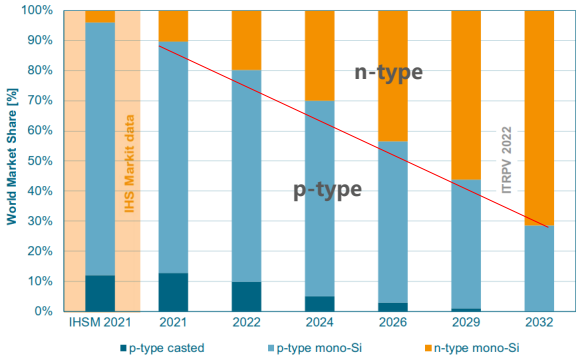
ASTRO N
Product White Paper

Contents

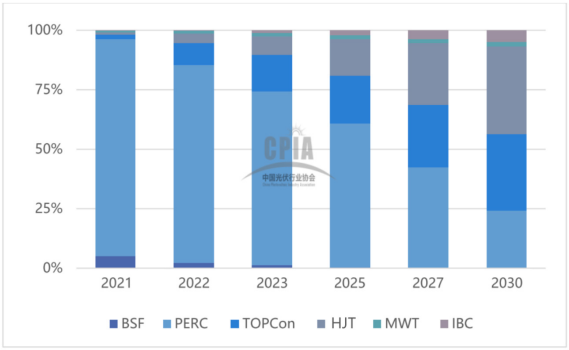
01 PART Background

Improving efficiency and reducing cost are not only the most important ways to reduce the levelized cost of electricity (LCOE) of photovoltaic (PV) power generation, but also the driving force to promote the continuous progress of technology. As the basic unit for converting solar energy into electrical energy, solar cells directly determine the conversion efficiency of PV system and have a significant impact on the LCOE of power stations.The main method to improve the conversion efficiency of solar cells is technical optimization or iteration.

The p-type PERC cell, which is the mainstream technology in the current industry, has been gradually approaching its upper limit of conversion efficiency of 24.5% after continuous technical optimization, and the progress of efficiency improvement has slowed down significantly. Therefore, the PV enterprises are accelerating to the iterative upgrading of new cell technology. The higher efficient n-type cell technologies represented by TOPCon have become the important directions of industry technology development due to their high potential for efficiency improvement and continuous reduction of investment cost. In recent years, n-type cell technologies have developed rapidly and accelerated industrialization, which will have a broad market prospect. According to the authoritative industry forecast in the figures below, p-type PERC is still the mainstream cell technology before 2025, however, n-type cells will develop rapidly and are expected to replace p-type cells as the mainstream technology in five years.



(Source: International Technology Roadmap for Photovoltaic (ITRPV) 13th version, Mar. 2022)



(Source: China PV industry development Roadmap of CPIA 2021 version, Feb. 2022)

Trend in the market share of different solar cell technologies (2021~2030)

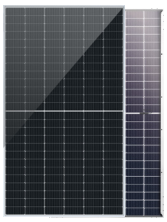
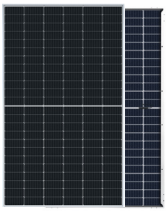
Astronergy has iteratively upgraded the ASTRO series products over the years, and now after the in-depth research on n-type technology for several years and the accumulation of industrial practice, Astronergy officially launched the ASTRO N series, a new generation of PV modules in April 2022, initiating a new track for n-type products.

ASTRO N improves the product performance in all aspects compared with current mainstream products, which can not only further reduce the LCOE of PV power generation and bring more benefits to customers, but also effectively promote the rapid development of the PV industry and contribute to the transition of global clean energy .

02 PART ASTRO N Series Products

The ASTRO N series, including ASTRO N6 with 210mm wafer technologies, ASTRO N5 and ASTRO N5s with 182mm wafer technologies, offer the new product solutions that perfectly suit for all scenarios such as utility scale, large commercial & industrial (C&I) and overseas residential rooftop applications, and meet the real requirements of various customers. All series of products adopt standard size to achieve the convenience and maximum value of products in the application.

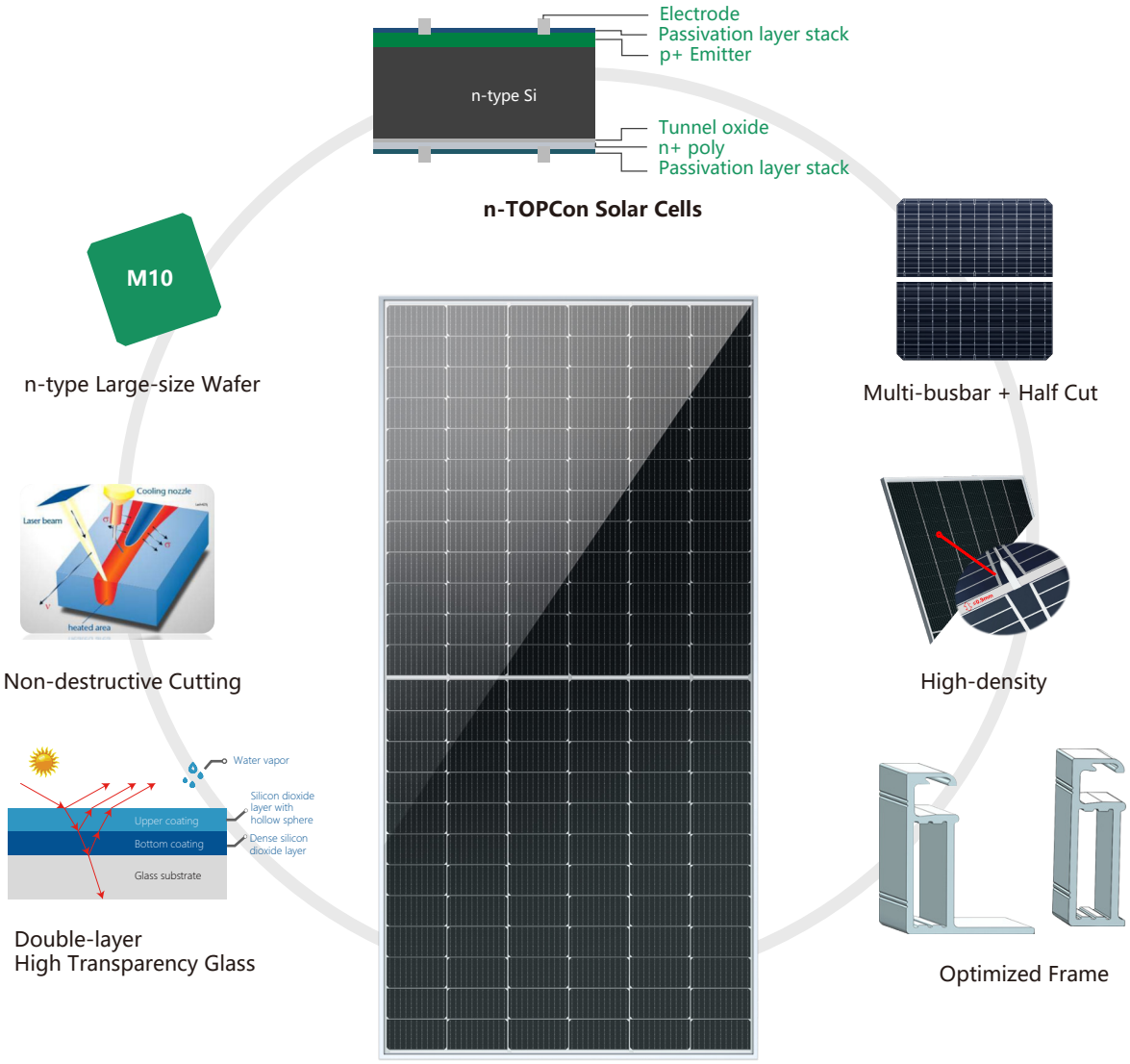
Bifacial double-glass ASTRO N5 PV module is now the mainly recommended product, which has 72 and 78 models. With characteristics of large size and high power, ASTRO N5 is suitable for utility scale and large C&I distributed PV power stations.ASTRO N5s has types of white modules and high-end black modules, and both have double-glass types. ASTRO N5s series modules are suitable for residential PV rooftop due to characteristics of small size and light weight, aesthetical appearance and high efficiency.

Product Type	 **ASTRO N5-78** Utility Scale Application	 **ASTRO N5-72** Big C&I Application	 **ASTRO N5s** Overseas Rooftop Application	 **ASTRO N5s (black)** Overseas Rooftop Application
Module dimension [mm]	2465×1134×35	2278×1134×30	1722×1134×30	1722×1134×30
Maximum power (Pmax) [W]	**630**	**580**	**440**	**430**
Voltage at maximum power point (Vmpp) [V]	46.45	43.11	32.61	32.27
Current at maximum power point (Impp) [A]	13.56	13.45	13.49	13.33
Open-circuit voltage (Voc) [V]	56.21	51.30	38.80	38.40
Short-circuit current (Isc) [A]	14.19	14.28	14.30	14.09
Module efficiency	**22.5%**	**22.5%**	**22.6%**	**22.0%**
Weight [kg]	34.7	32.1	21.3	21.3
Bifaciality	**80±5%**	**80±5%**	/	/
Temperature coefficient of Pmax (γ-Pmp)	**-0.30%/°C**			
Temperature coefficient of Isc (α-Isc)	+0.043%/℃			
Temperature coefficient of Voc (β-Voc)	-0.24%/℃			
Warranty	**12-years** product warranty **30-years** linear power warranty		**12-years (15-years optional)** product warranty **30-years** linear power warranty	
Power attenuation warranty	First year degradation≤**1%**, annual degradation≤**0.4%**			

03 PART Technical Innovations

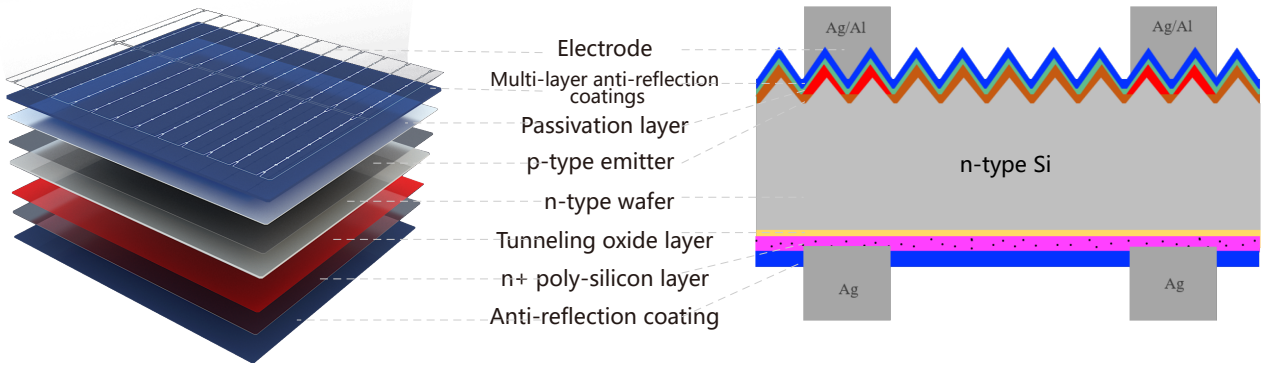
3.1 Core Technologies

ASTRO N not only adopts the advanced technologies of ASTRO 5 and ASTRO 6 series, such as large-size silicon wafer, multi-busbar (MBB), half-cut, non-destructive cutting, high-density encapsulation and double-layer coatings glass, but also incorporates the latest R&D innovations of Astronergy in high-efficiency n-TOPCon cell technology, the n-type high quality silicon wafer and the optimized frame. All of these technologies make ASTRO N more competitive.



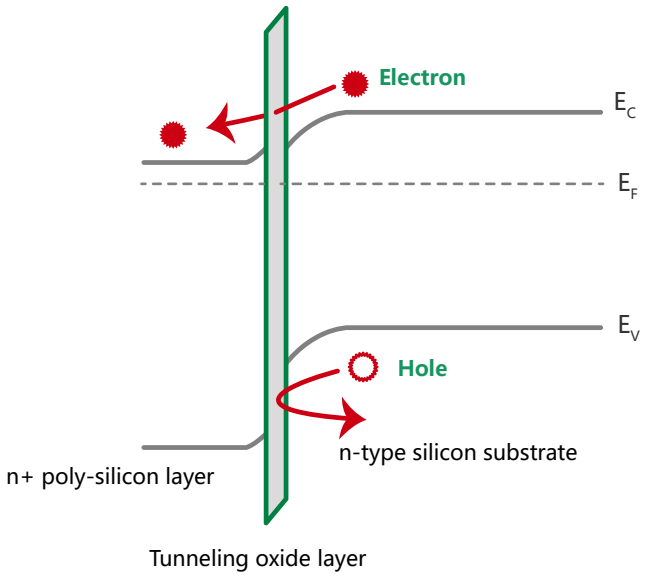
Core Technologies of ASTRO N

3.2 n-TOPCon Cell Technology



Cell structure of TOPCon

n-TOPCon refers to the tunnel oxide passivated contact technology on n-type silicon wafer. The cell structure is shown in the figure above. The front surface is essentially the same as that of the conventional n-PERT cell, the main difference is that an ultra-thin tunneling silicon oxide (SiO_2) layer and a thin highly doped polysilicon layer are deposited on the rear of the TOPCon cell. According to the quantum tunneling effect, the SiO_2 layer with a thickness of 1~2nm can not only allow electrons to pass through smoothly, but also prevent the recombination of holes. The passivation contact structure formed by SiO_2 layer and doped polysilicon layer can effectively reduce the surface recombination and metal contact recombination, thereby improving the open circuit voltage (Voc) and fill factor (FF) of the cells.



Band structure of TOPCon tunneling layer. The ultra-thin SiO_2 layer allows the majority carriers (photoelectrons) in the n-type silicon wafer to tunnel into the polysilicon layer, and blocks the minority carriers (photoholes) from crossing the interface, thus significantly reducing the interface recombination

PERC needs laser grooving on the back of the cell so that the aluminum on the rear can contact the silicon wafer to form a conductive path. However, the laser grooving not only increases the process steps and manufacturing cost, but also destroys the passivation effect of the grooved area. In contrast, TOPCon no longer needs laser grooving because the silver electrode on the rear can directly penetrate the rear anti-reflection (AR) coating and contact the doped polysilicon layer to form a good conductive path. Therefore, TOPCon can effectively improves the cell efficiency by passivating the entire rear side of the cell, meanwhile, it avoids the damage of the silicon wafer by the laser, which enables the use of thinner wafer.

The refractive index (n) of silicon wafer (n≈3.8) is quite different from that of the encapsulation film (n≈1.5). In order to reduce the reflection of sunlight at the interfaces, two- or three-layer silicon nitride (SiNx) AR coatings are commonly used in conventional cell processes, but these structures still cannot make full use of the physical and chemical properties of the films.

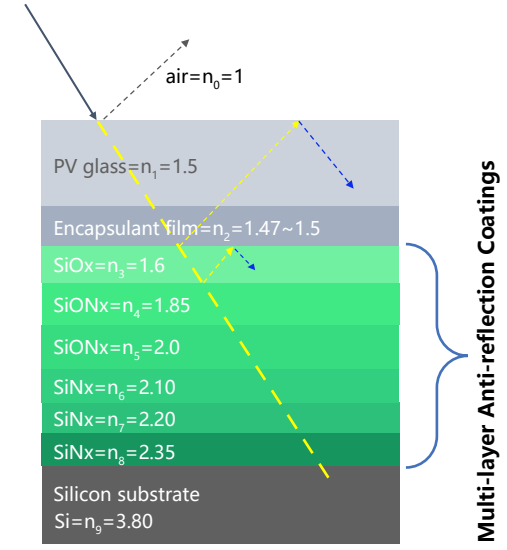
On the basis of TOPCon technology, a new multi-layer AR coatings process is also used in Astronergy n-type cell, further improves optical utilization, and effectively improves aesthetic appearance of the product

A

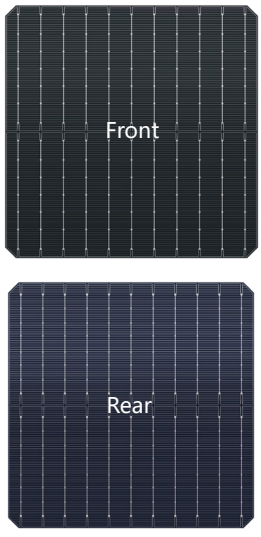
As shown in the figure below, the stacked structure is composed of silicon oxide (SiOx)/silicon oxynitride (SiONx-)/SiNx multi-layer films, and the refractive index of each layer is different. The refractive index of the entire structure gradually increases from the outer surface to the inner layer; therefore, the multi-layer AR coatings are fully optically matched with the encapsulation film and the silicon wafer to achieve a better anti-reflection effect.

B

Meanwhile, the surface color of TOPCon cell is darker and more uniform after adopting the multi-layer AR coatings process, which greatly alleviates the problem of color difference inside the cell and between cells, resulting in a high aesthetic appearance of ASTRO N series.



Structure of the multi-layer AR coatings on the front side of TOPCon cell



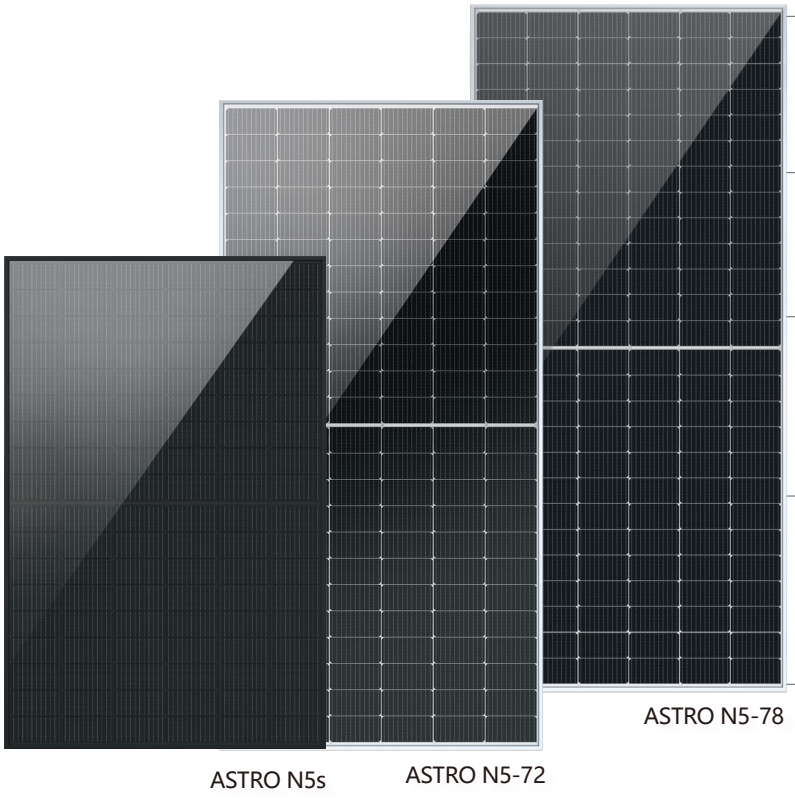
Front and rear views of TOPCon cell

04 PART Performance Advantages

4.1 Core Advantages

Integrating several advanced cell and module technologies of Astronergy, the ASTRO N series has the characteristics of high module power, high module efficiency, high energy yield per watt, high reliability and high aesthetic appearance, which can provide customers with a higher performance/price ratio option.

Higher Performance/Cost Ratio
Lower BOS cost and LCOE



High Module Power
Up to 630W/580W
Higher than PERC 15~30W

High Module Eff 22.5%+
High eff cell
High density design

High Energy Yield
Gain of 3.5%+ than PERC
Higher bifaciality(80%)
Better temperature coefficient (-0.30%/°c)

High Reliability
Lower LID & LETID
Better product warranty
1st year degradation ≤1.0%
Annual degradation ≤ 0.40%

High Aesthetic
More consistent cell color
Better product appearance

Core Advantages of ASTRO N

Compared with the PERC module which is the mainstream product in the current market, ASTRO N has more advantages in terms of bifaciality, temperature coefficient, operating temperature, low-light performance, LID and LETID, etc., all of which are the key factors that directly affect the power generation of the module.

4.2 Bifaciality

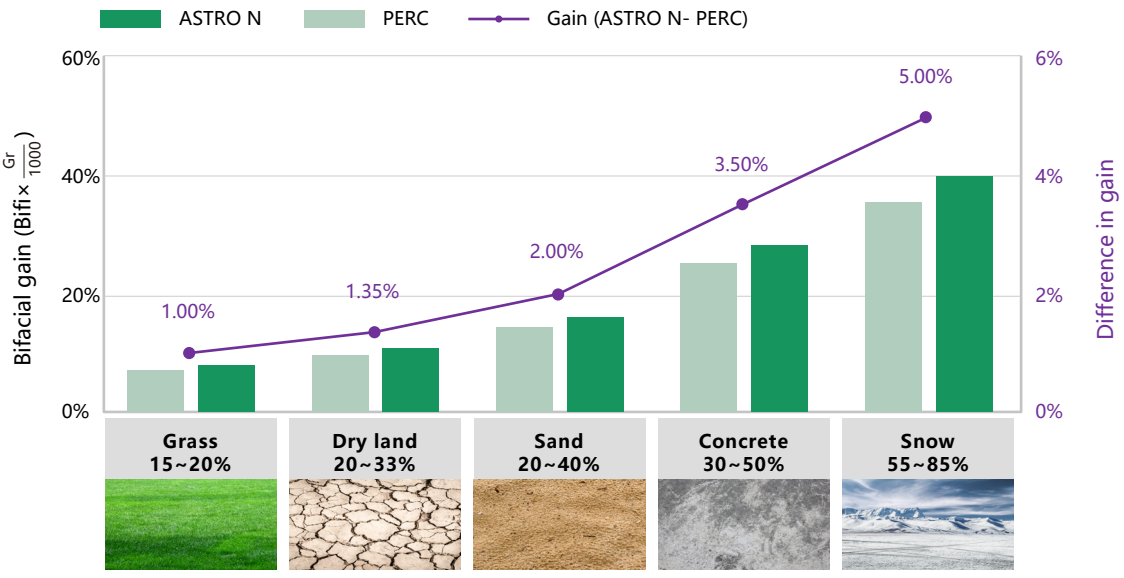
Bifaciality is the percentage of rear-side power to front-side power tested under standard test conditions (STC), which is an important parameter to characterize the performance of bifacial modules. ASTRO N adopts the TOPCon bifacial cells of Astronergy. While ensuring the high efficiency of the front side, the TOPCon cells is also improved the efficiency of rear side by optimizing the rear films and rear grid fingers design. Therefore, the bifaciality of ASTRO N is up to 80% which is about 10% higher than that of the conventional PERC module.

The energy yield gain of the bifacial module is not only affected by the bifaciality of the module itself, but also by the irradiance on the rear side (Gr). The Gr is related to ground reflectivity, environmental irradiance and real installation condition. In a project site, the higher the ground reflectivity, the larger the Gr. The Gr under the bifacial nameplate irradiance (BNPI) and the bifacial stress irradiance (BSI) as defined in IEC 61215:2021 standard are 135 W/m^2 and 300W/m^2, respectively.

According to the measurement of current-voltage characteristics of bifacial modules described in the IEC TS 60904-1-2 standard, the equivalent irradiance (G_E) is expressed as follows:

$$G_E = 1000 + Bifi \times Gr = 1000 \times \left(1 + Bifi \times \frac{Gr}{1000}\right) \propto P_{front} \times \left(1 + \frac{P_{rear}}{P_{front}}\right)$$

Where 1000 represents the irradiance under STC, Bifi is the bifaciality of the module, P_{front} is the front-side power under STC, and P_{rear} is the rear-side power under the real Gr. Therefore, the bifacial gain (P_{rear} / P_{front}) can be approximately represented by Bifi×(Gr/1000) , which represents the gain in the rear-side power of the bifacial module compared with the front-side power.



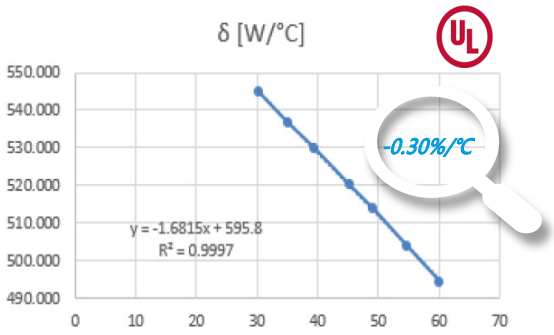
Comparison of bifacial gain between ASTRO N and PERC module under different ground

The above figure shows the comparison of the bifacial gain between ASTRO N and PERC bifacial modules in the application scenarios of grass, dry land, sand, concrete and snow with different ground reflectivity. Compared with PERC module, the significant advantage of bifaciality increases the bifacial gain of ASTRO N by 1~5%, and the maximum gain is in the fresh snow scenario with the highest reflectivity. Therefore, when the ASTRO N series modules are applied to the PV power stations located on the ground with high reflectivity, the excellent bifaciality of ASTRO N can be more fully utilized to achieve higher power output.

4.3 Temperature Coefficient

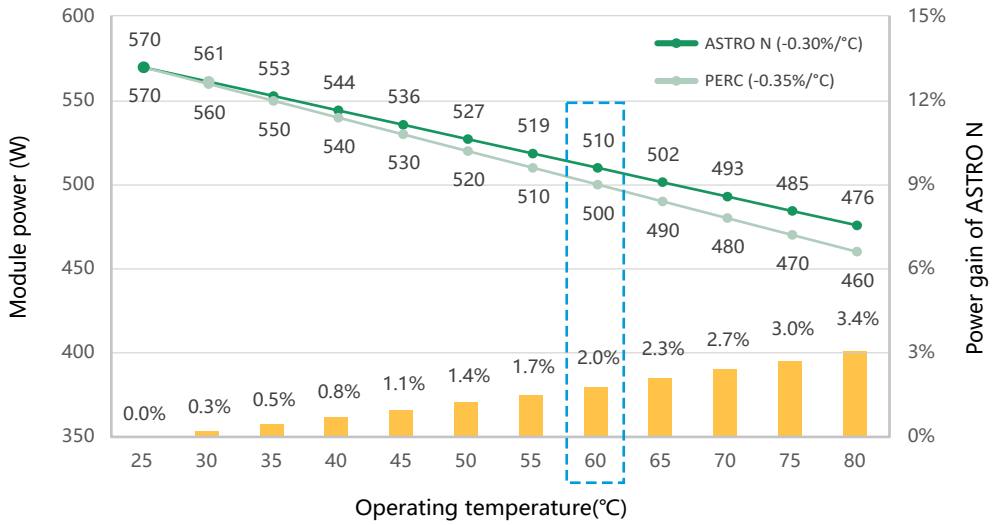
The temperature coefficient is the rate at which the physical properties of a material or device change with temperature, which can be used to directly compare the performance of various products in high temperature environment. The power output of crystalline silicon modules is negatively correlated with temperature, indicating that the Pmax temperature coefficient is negative. Meanwhile, the operating temperature of outdoor PV modules is generally much higher than the temperature under STC (25°C). Therefore, there is some loss of module power at high operating temperatures.

The ASTRO N series show excellent characteristic in terms of temperature coefficient. Certified by the third-party authoritative organization UL, the Pmax temperature coefficient of ASTRO N is only -0.30%/°C, which is significantly better than that of the p-type PERC module of -0.35%/°C. This is due to the high open-circuit voltage characteristic of the TOPCon cells used, which reduces the temperature sensitivity of ASTRO N modules.



Relationship between the output power of ASTRO N and the temperature temperature coefficient of ASTRO N is only -0.30%/℃ tested by UL.

For comparison, it is assumed that the module powers of ASTRO N and PERC are the same under STC, both of which are 570W as shown in the following figure. When the operating temperature is higher than 25°C, the output power of ASTRO N is higher than that of PERC. Moreover, the higher the operating temperature, the greater the power gain of ASTRO N over PERC. For example, when the operating temperature is 60°C, the real output power of ASTRO N is 10W higher than that of PERC, and the power gain is 2%. Therefore, the better temperature coefficient of ASTRO N can bring the higher power generation revenue and improve the profitability of power stations, especially in the high temperature application scenarios.



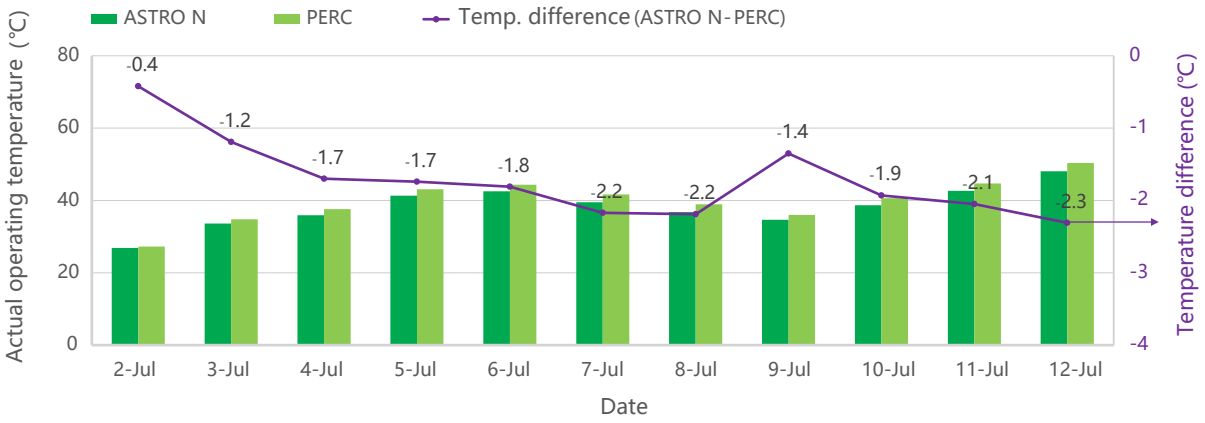
Assuming that ASTRO N and PERC module have the same power of 570W under STC, their real powers and the power gain of ASTRO N at different operating temperatures

4.4 Operating Temperature

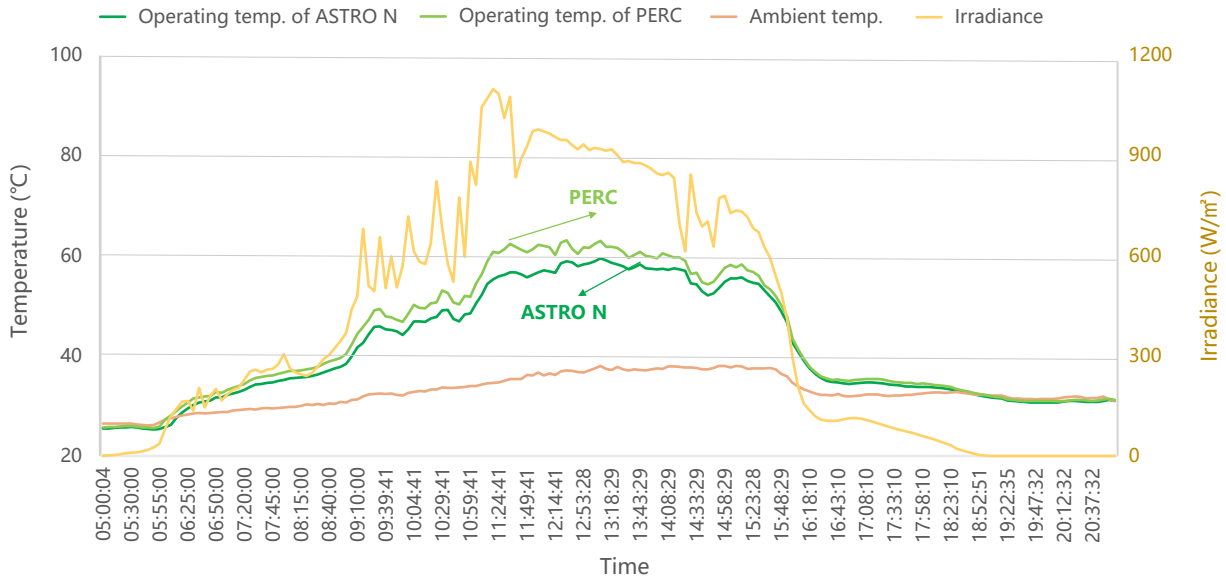
Because of its high photoelectric conversion efficiency, ASTRO N can convert more solar energy into electricity, while radiating less thermal energy accordingly. Therefore, ASTRO N has a lower operating temperature than PERC module in practical power station applications.

At the outdoor demonstration power station of Astronergy located in Haining, Zhejiang province, China, the operating temperatures of ASTRO N and PERC modules were monitored and compared during the summer high temperature period in early July 2021. It was found that the real operating temperature of ASTRO N was about 1.6°C lower than that of PERC modules on average.

According to the analysis of different times on a typical sunny day, the advantage of lower operating temperature of ASTRO N was more noticeable when the irradiance was high.



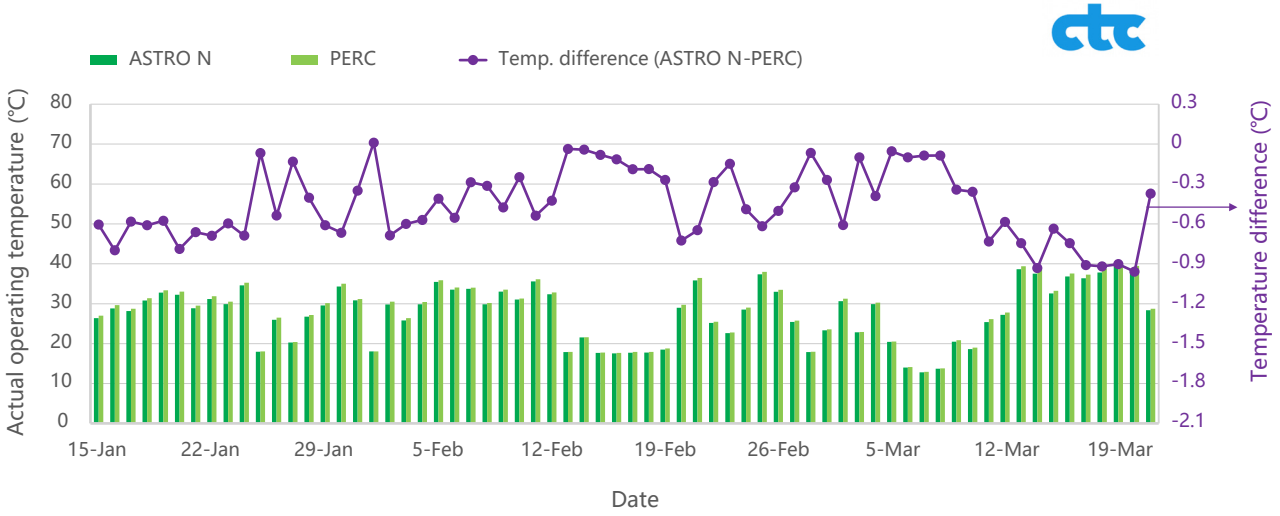
Comparison of the real operating temperature between ASTRO N and PERC modules in summer (Daily average temperature from 7:00~17:00)



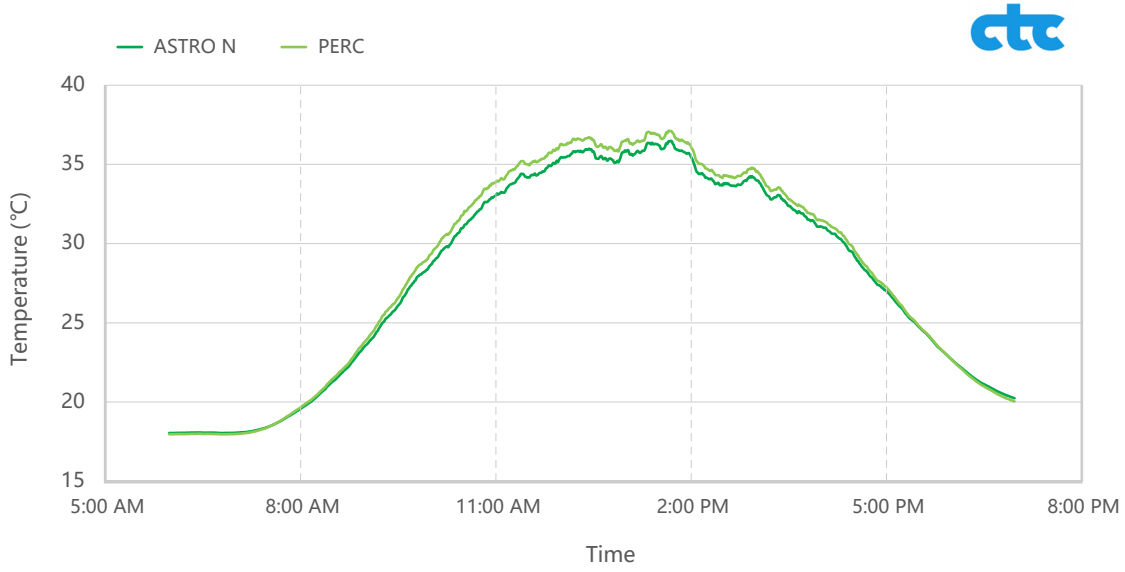
Comparison of the real-time operating temperature between ASTRO N and PERC modules on a typical sunny day. The advantage of lower operating temperature of ASTRO N was more prominent at 9:30~16:00

The advantage of lower operating temperature of ASTRO N was also confirmed by the third-party demonstration power stations.

At the outdoor demonstration base of China Building Material Test & Certification Group (CTC) located in Hainan province, China, the average operating temperature of ASTRO N was 0.5℃ lower than that of PERC modules during the relatively low temperature period from January to March. The maximum temperature difference reached about 1°C when the irradiance was high at noon.

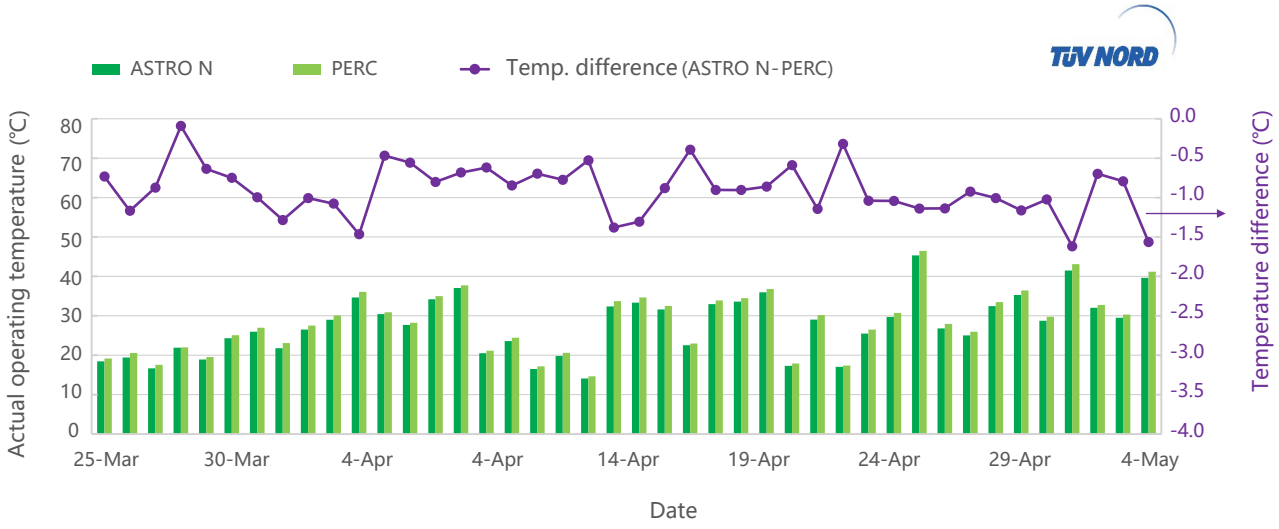


Comparison of the real operating temperature between ASTRO N and PERC modules at the outdoor demonstration base of CTC located in Hainan

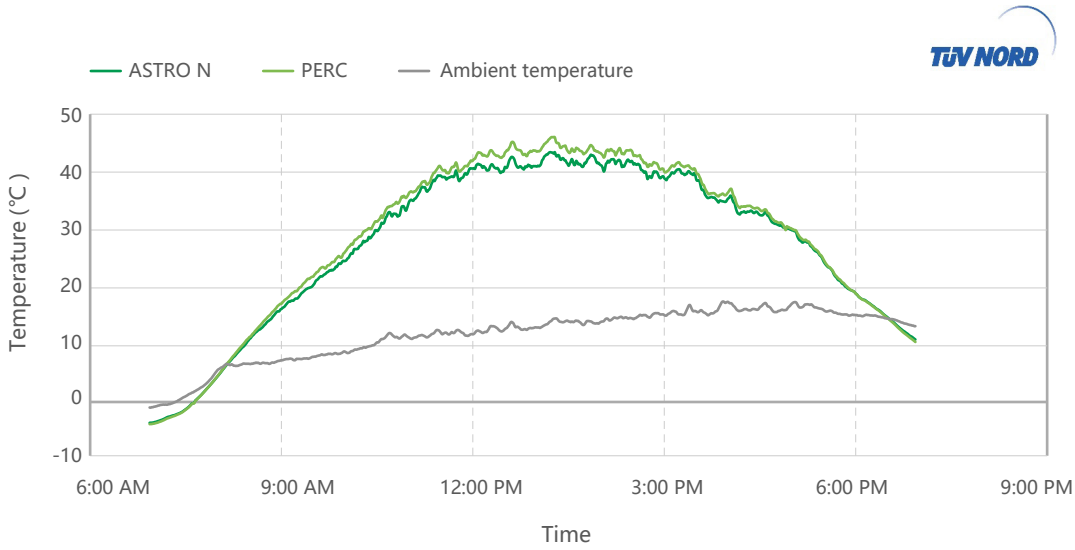


At the outdoor demonstration base of CTC located in Hainan, the comparison of the real-time operating temperature between ASTRO N and PERC modules on a typical sunny day. When the radiance is high at noon, the advantage of lower operating temperature of ASTRO N was more prominent, and the maximum temperature difference was about 1°C

At the outdoor demonstration base of TÜV Nord located in Yinchuan, Ningxia autonomous region, China, the average operating temperature of ASTRO N was 0.9℃ lower than that of PERC modules from March to early May. The temperature difference reached its maximum at noon every day when the irradiance was high.



Comparison of the real operating temperature between ASTRO N and PERC modules at the outdoor demonstration base of TÜV Nord located in Ningxia

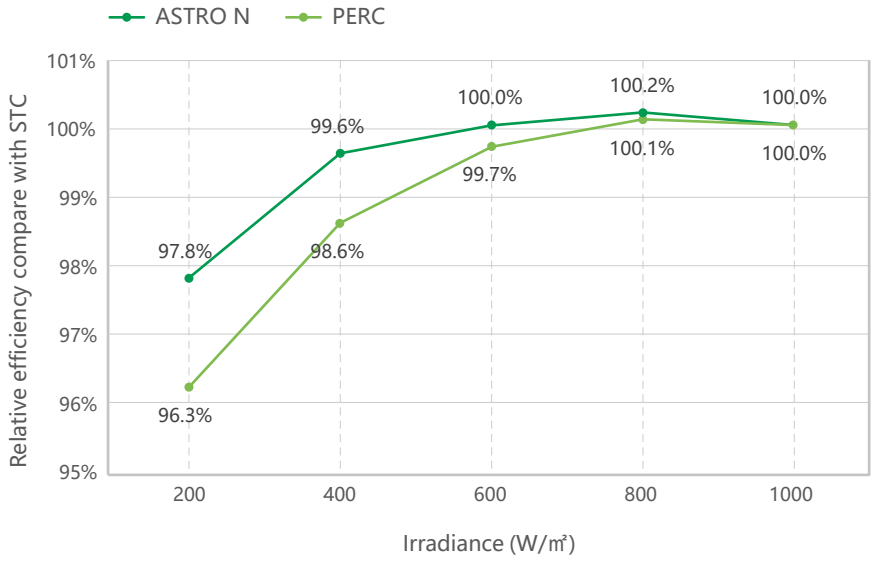


At the outdoor demonstration base of TÜV Nord located in Ningxia, the comparison of the real-time operating temperature between ASTRO N and PERC modules on a typical sunny day. When the radiance was high at noon, the advantage of lower operating temperature of ASTRO N was more prominent.

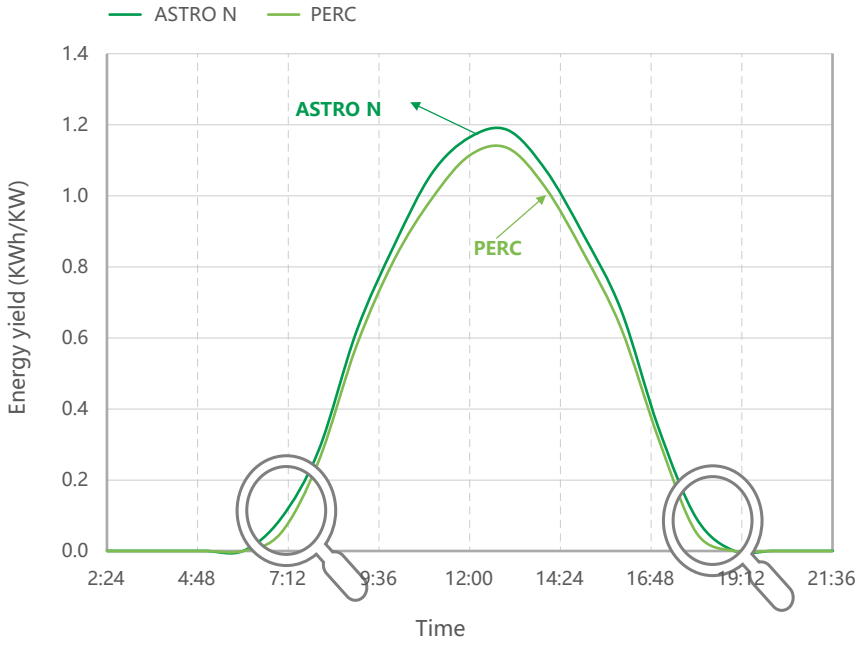
In conclusion, all the measured data from several demonstration power stations in different climates indicate that the operating temperature of ASTRO N is lower than that of PERC modules, and the higher the temperature, the greater the temperature difference. Due to the negative temperature coefficient of Pmax, the lower operating temperature characteristic of ASTRO N can bring higher power output and directly increase the energy yield gain of the power stations!

4.5 Low-light Performance

The nominal power of PV module is the test value under STC. However, the real irradiance of outdoor power stations is usually lower than STC of 1000W/m² in most of the time. The module efficiency under low irradiance will have a certain loss compared with under STC, which is called the low-light performance. After being tested by the third-party organization UL, the low-irradiance performance of ASTRO N is 97.8% at 200W/m², which is 1% higher than that of PERC module. This indicates that ASTRO N has better low-light performance.



Relative efficiency of ASTRO N and PERC module as a function of irradiance



Comparison of the energy yield between ASTRO N and PERC modules on a typical sunny day. ASTRO N also shows better power generation performance in the morning and evening

As shown in the figure on the left, the power generation of ASTRO N and PERC modules in a power station is compared on a typical sunny day. It is found that ASTRO N is superior to PERC modules in energy yield per watt in the morning, noon and evening, especially in the case of low-light conditions in the morning and evening, ASTRO N also shows better power generation capacity, which is benefited from the better low-light performance of ASTRO N.

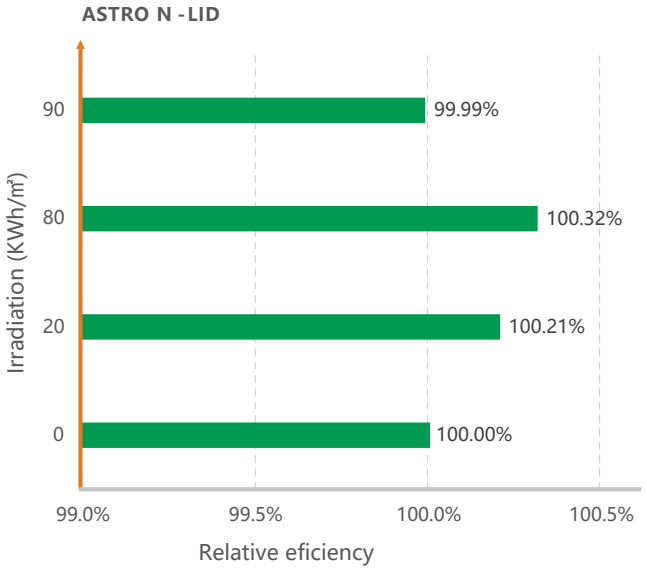
In short, ASTRO N not only has high energy yield under STC, but also has good power generation performance under low irradiance such as cloudy days. This can guarantee the energy yield of the power station.

4.6 LID & LETID

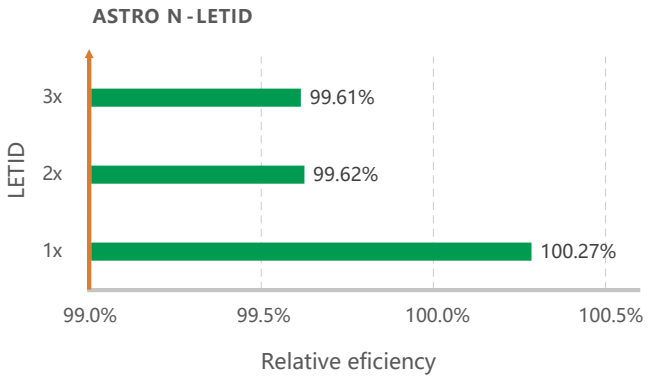
The power degradation under illumination is one of the important characteristics of module reliability, including light induced degradation (LID) and light and elevated temperature induced degradation (LETID). Both of these degradations are generated by light irradiation, but their degradation mechanisms are different. LID is mainly due to the formation of B-O complex defects by oxygen (O) and boron (B) in the silicon wafer, which reduces the minority carrier lifetime and leads to power attenuation. The mechanism of LETID is not yet completely clear, at present the widely accepted explanation is the hydrogen induced degradation (HID). The hydrogen bonds of passivating impurities and defects are easily destroyed by high temperature and light exposure, which induce the formation of recombination centers and lead to degradation. LETID is accelerated at high temperatures.

The LID and LETID of PERC module are reduced to relatively low values by improving the quality of silicon wafer and optimizing the cell technology and process. But in contrast, ASTRO N has lower LID and LETID than PERC due to its high efficiency cell technology and high-quality n-type silicon wafer, which not only eliminates the LID caused by B-O complex defects, but also has a higher minority carrier lifetime and a higher tolerance to metal impurities.

As shown in the figures, the LID of ASTRO N is only 0.01% after exposure of 90KWh/m^2, which is almost negligible. The power of ASTRO N was not attenuated after LETID tested by PI Berlin method. Even after three times of the LETID test, the attenuation was still only 0.39%.



LID of ASTRO N is only 0.01% after light exposure of 90 kWh/m²
Test conditions:
irradiance of 1000W/m², connected load with current of Impp



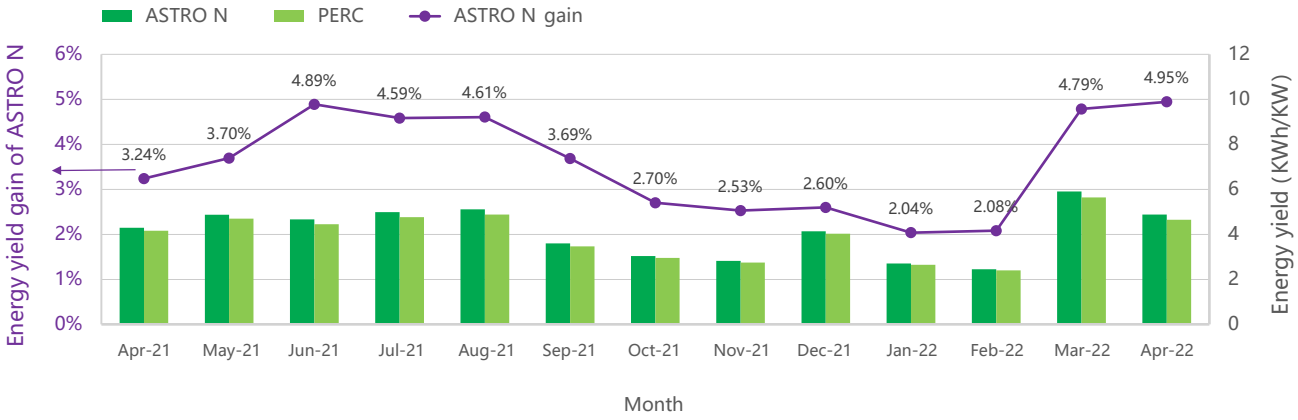
Due to higher reliability, lower LID and LETID, ASTRO N can provide better prouct power warranty than PERC module.

Attenuation of ASTRO N is only 0.39% after triple PI Berlin LETID tests
LETID - PI Berlin method:
75±3℃, first connect a current of 1A for 162 hours, then 10A for another 162 hours

4.7 Energy Yield per Watt

In summary, ASTRO N has the advantages of higher bifaciality, better temperature coefficient, better low-light performance, lower operating temperature, and lower LID and LETID than PERC module. These key features ensure the higher energy yield of ASTRO N.

In the power station mounted on fixed racking in Haining, Zhejiang province, China, an outdoor empirical comparison has been carried out for more than one year. The data shows that the energy yield per watt of ASTRO N is about 3.57% higher than that of PERC modules, and the gain even exceeds 4.5% in summer!

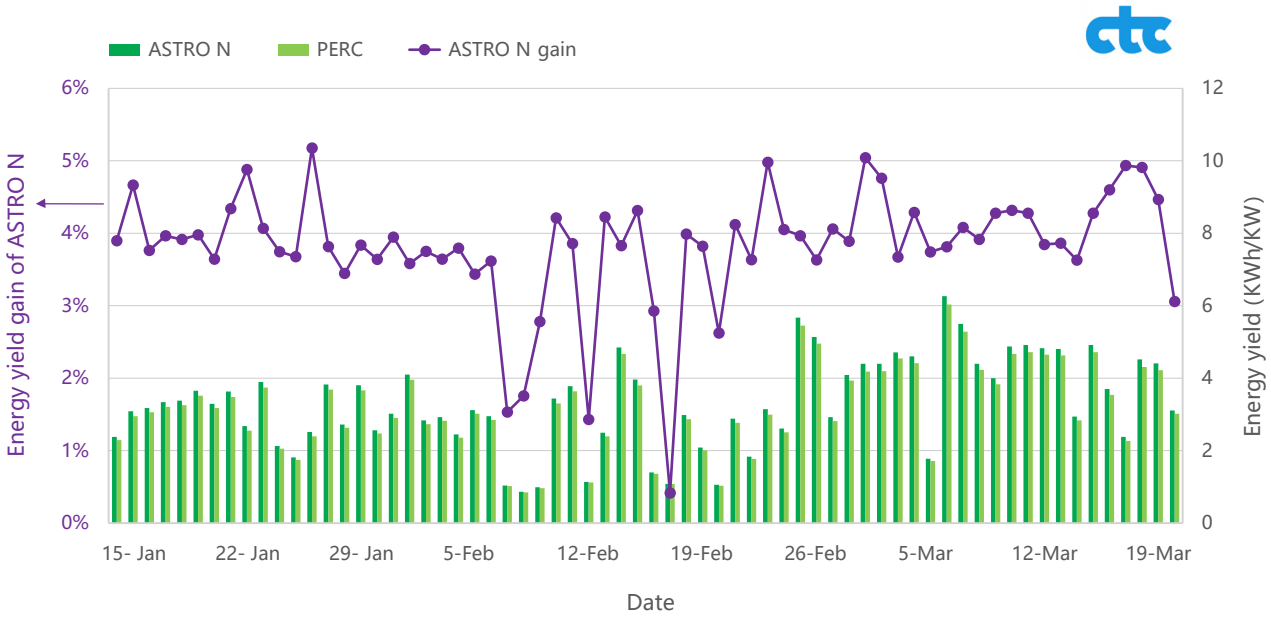


Comparison of the normalized energy yield per watt between ASTRO N and PERC modules at the outdoor demonstration base of Astronergy located in Haining

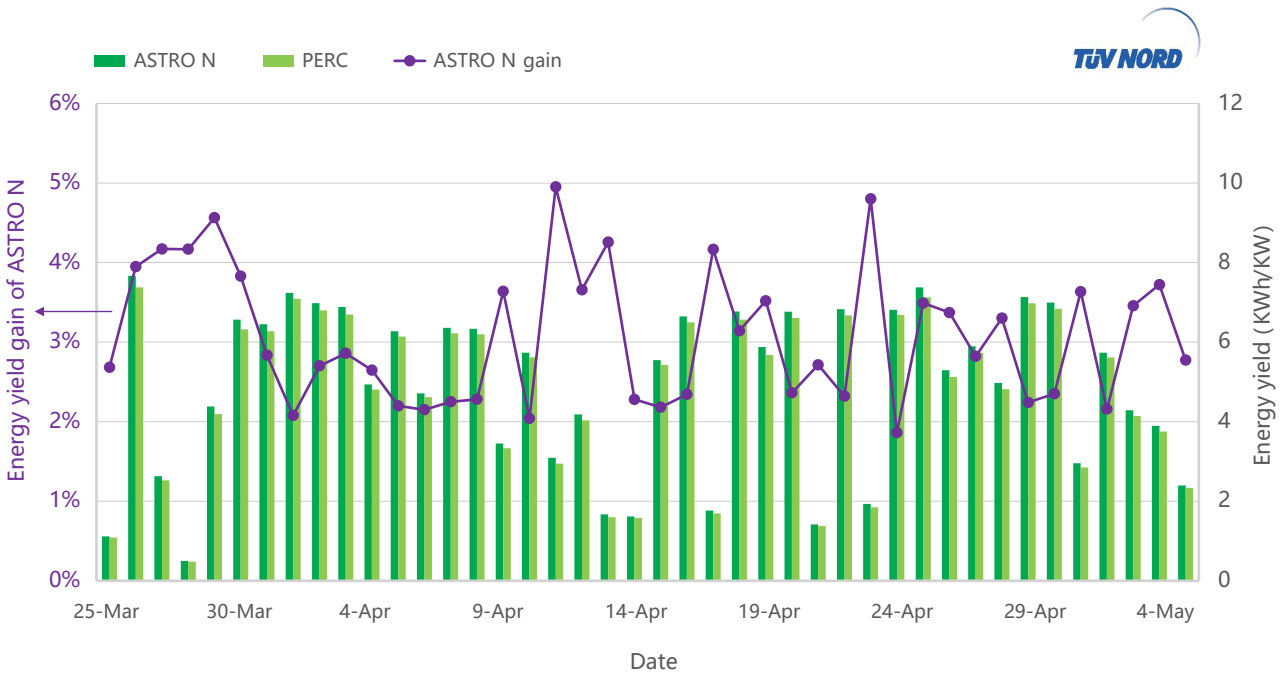
Real view of the outdoor demonstration base of Astronergy
120°18 '-120°52' E, 30°15 '-30°35' N
fixed racking, tilt:20°, ground clearance:1.2m

At the demonstration bases of CTC and TÜV Nord located in Hainan and Ningxia respectively, ASTRO N also shows better power generation performance. Compared with PERC modules, the average energy yield gains per watt of ASTRO N are 3.82% and 3.07% in the hot-humid climate of Hainan and the dry climate of Ningxia, respectively.

In conclusion, several empirical results consistently show that ASTRO N has superior power generation performance to PERC in most application scenarios.



Average energy yield per watt of ASTRO N is about 3.82% higher than that of PERC modules at the demonstration base of CTC located in Hainan



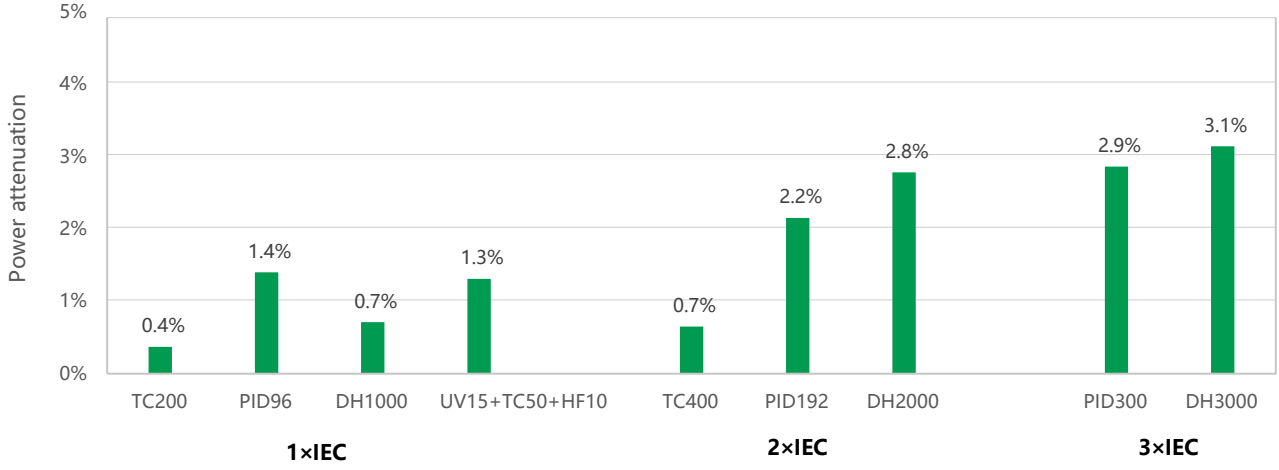
Average energy yield per watt of ASTRO N is about 3.07% higher than that of PERC modules at the outdoor demonstration base of TÜV Nord located in Ningxia

05 PART Performance Assurance and Warranty

5.1 Reliability Assurance

In addition to the advanced technology, another important characteristic of the ASTRO N series is high reliability. From the beginning of the design, we strictly follow the product development system for quality control, and ensure that all design risks can be fully assessed and avoided through product design assurance, process quality control, inspection and monitoring, etc.

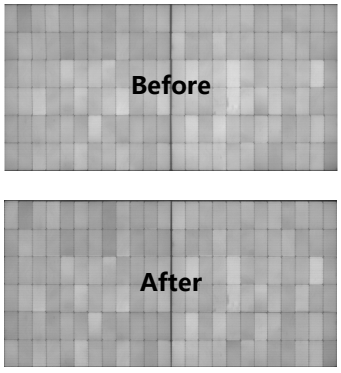
As shown in the figure below, the power attenuations of ASTRO N are only 0.4%~1.4% in various IEC standard aging tests, and the key items such as TC, PID and DH have even passed multiple strict tests. All these results fully verify the high reliability of ASTRO N.



ASTRO N shows excellent performance in various IEC standard and multiple aging tests

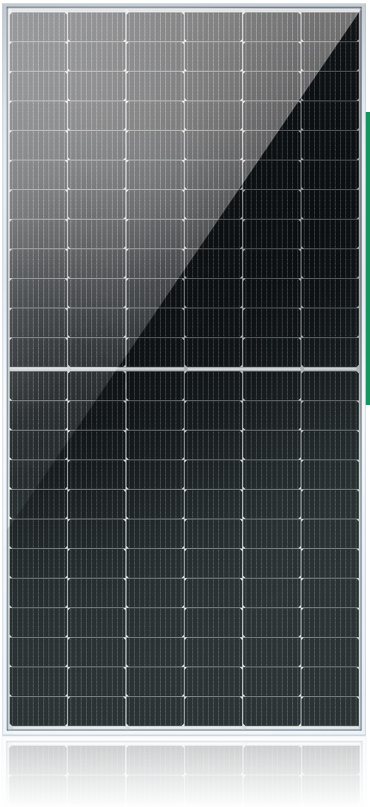
On the basis of adopting non-destructive cutting and MBB technologies that can improve reliability, ASTRO N further strengthens the mechanical property by improving the aluminum material, optimizing the section design of frame and enlarging the vertical cavity. After the static mechanical load test of 5400Pa positive load and 2400Pa negative load under four-point mounting with clamps, the power attenuation of ASTRO N5 is only 0.12%, and there is no virtually crack shown in EL image.

The results confirm that the large-size products of ASTRO N also have excellent mechanical properties and fully meet the requirements of mechanical load under various installation conditions.



EL images of ASTRO N5 before and after the mechanical load test

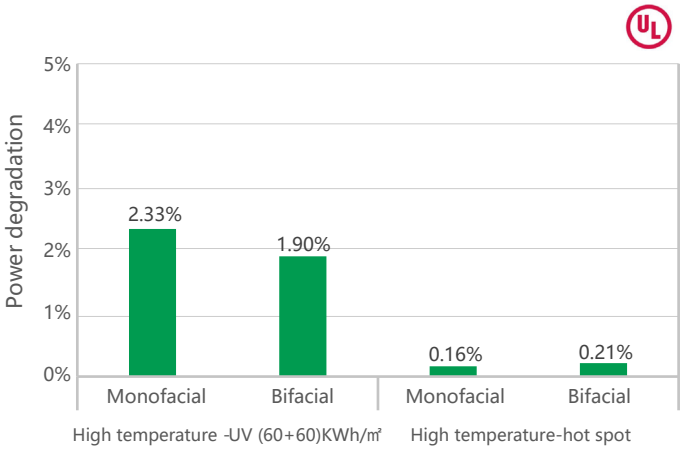
ASTRO N has excellent product performance in high temperature environment as described previously, meanwhile, the reliability at high temperature has been also fully evaluated in accordance with IEC TS 63126:2020. According to temperature level 1 of the standard, the module temperature is 10°C higher than that of the IEC61215 standard in the process of strict high temperature aging test.



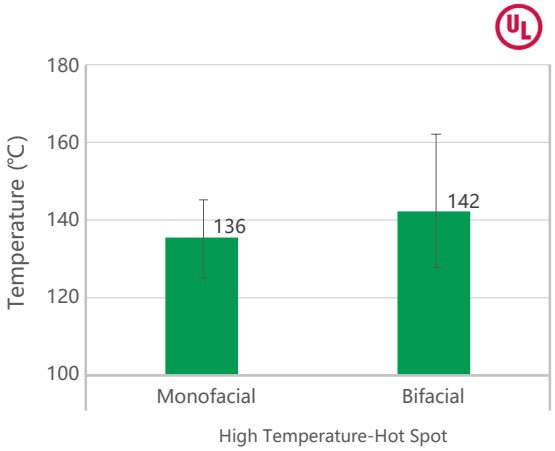
The results certified by the third-party organization UL show that ASTRO N5 still has excellent UV stability and hot spot endurance at high temperature

The UV test is performed by increasing the temperature to 60℃, both monofacial and bifacial modules of ASTRO N5 have passed the durability test at high temperature with UV irradiation up to 120KWh/m^2. The attenuation of module power is 1.9%~2.33% and there is no problem of appearance quality.

After the high temperature hot spot test at the module temperature of 70°C, the power attenuation of ASTRO N5 monofacial and bifacial modules are only 0.16% and 0.21%, respectively, and the average hot spot temperatures are 136°C and 142°C, respectively.



Power attenuation of ASTRO N5 after high temperature aging tests



Average hot spot temperature of ASTRO N5 during high temperature hot spot test

ASTRO N successfully passed the strict high temperature aging tests, which verifies that ASTRO N also has excellent reliability and stability even in high temperature environment and demonstrates the "high temperature value" of ASTRO N.

5.2 Warranty

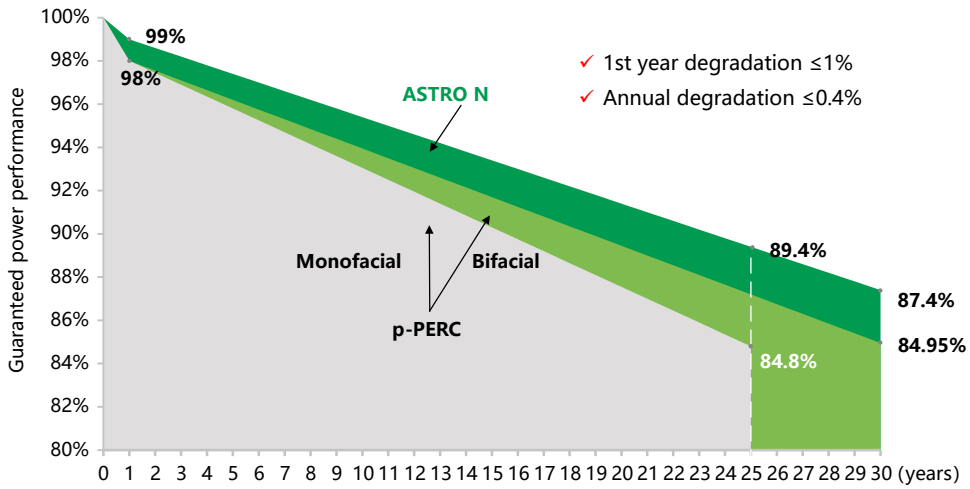
Based on the excellent characteristics of the products and the strict quality and reliability assurance system of Astronergy, ASTRO N series provide the industry-leading warranty: 12 years product and workmanship warranty and 30 years power warranty; the power degradation in the first year is ≤1%, and the annual linear power degradation is ≤ 0.4%.

25 years later	Promise	30 years later
The power of ASTRO N is not lower than 89.4% of the rated power, which is 4.6% higher than that of the PERC monofacial module with a 25 years power warranty		ASTRO N guarantees a final power output at least 87.4% of the rated power, which is 2.5% higher than PERC bifacial module.

The better warranty ensures that ASTRO N has superior power generation performance throughout the lifetime of the power stations which can generate more clean energy, and the sustainability of low-carbon characteristic of ASTRO N is also guaranteed.

30years
Power Warranty

12years
Product and Workmanship Warranty



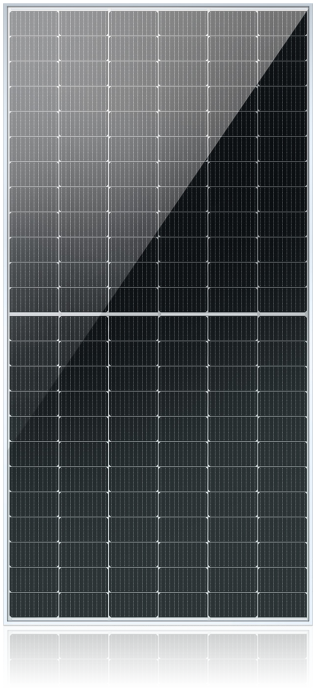
Leading product and power warranty of ASTRO N

06 PART Customer Value

6.1 Transportation Cost

Due to the higher module power characteristic, ASTRO N has more freight capacity of power than the same sized PERC module under the same transportation condition, therefore, the transportation cost per watt of ASTRO N is lower.

Taking ASTRO N5 bifacial module as an example. In addition to the high module power characteristic, ASTRO N5 adopts the latest frame design, which not only ensures the high reliability of product, but also allows more modules to be placed in each pallet. Therefore, ASTRO N5 can effectively reduce the transportation cost.



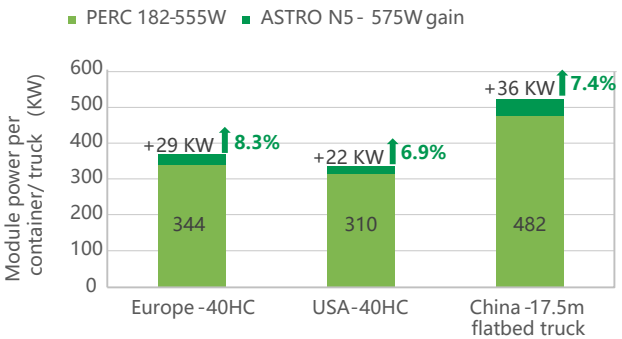
USA and Europe (40HC container)

Considering the weight limit of trucks, the loading power of ASTRO N5 per container is 22KW~29KW higher than that of the PERC 182 modules, an increase of 6.9%~8.3%. The ocean freight cost of ASTRO N5 can be saved by 0.6~0.7 fen RMB per watt.

China (17.5m flatbed truck)

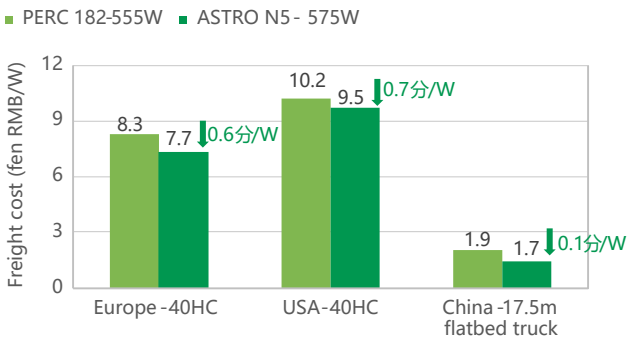
The loading power of ASTRO N5 per truck is 36KW more than that of the PERC 182 modules, an increase of 7.4%, and the land freight cost per 1,000 kilometers is reduced by about 0.1 fen RMB per watt.

It can be seen that the transportation costs of ASTRO N in different countries and regions are reduced compared with PERC. In case of rising ocean freight cost, ASTRO N module's advantage of lower transportation cost will be more prominent.



Comparison of the loading power per container or truck between the ASTRO N5 bifacial modules and the p-type 182 bifacial 555W modules

(Weight limit: Europe, USA and China are 22, 19.5 and 30.5 tons, respectively)



Comparison of the freight costs to different countries and regions between ASTRO N5 and p-type 182-555W modules

(Benchmark: the freight costs per 40HC container from China to USA and Europe are 4,500 and 4,100 US dollars, respectively, and the freight cost for 1,000 kilometers in China is 9,000 CNY per truck. 1 fen RMB = 1/7 cent)

6.2 BOS and IRR - Residential and C&I Applications

The balance of system (BOS) cost refers to the system cost excluding photovoltaic modules, including the costs of main equipment such as inverters, mounting structure, cables and electrical equipment, as well as the other related costs such as land, installation and construction, project design and acceptance, etc. The BOS costs in different countries and regions have different proportions in the cost of the whole PV system, which is lower in China and higher in Europe and America. In these high-cost regions, ASTRO N can effectively reduce the BOS cost due to its characteristics of high power and high efficiency.

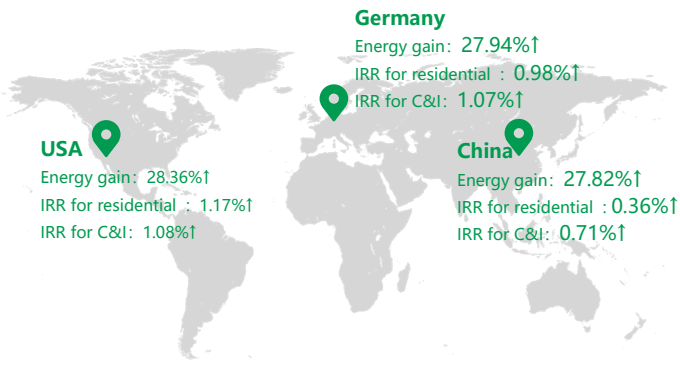
ASTRO N5s and ASTRO N5 are compared with the same sized PERC modules in three typical PV markets of China, Germany and USA. In the scenarios of residential and C&I applications, the number of installed modules of a project is the same due to the limitation of installation area, therefore, the installed capacity of ASTRO N is 3.6%-4.8% higher than that of PERC modules because of the higher power characteristic of ASTRO N. Finally, ASTRO N can reduce the costs per watt of cables, PV racking system, inverters, etc., and the BOS cost can be reduced by 3.9%.

Module type	PRRC	ASTRO N5s/N5	ASTRO N vs PRRC
Module quantity (pcs)	20/175		/
Module power (W)	415/545	435/575	**+20W**
System capacity (kWdc)	8.3/97.1	8.7/100.6	**3.6%-4.8%**
Power temp. coef.(%/°C)	-0.35	-0.30	**-0.05**
1st year degradation	2.00%	1.00%	**-1.00%**
Annual degradation	0.55%	0.40%	**-0.15%**
Lifetime (year)	25	30	**5**
Lifetime Energy Yield (kWh)	/		**+27.8%~28.4%**
BOS cost			**-3.9%**
Module premium (¢/W)			**1**
IRR			**+0.36%~1.17%**

Comparison of main parameters between ASTRO N and PERC modules in residential and C&I PV projects

Compared with the mainstream PERC monofacial products with a power warranty of 25 years, ASTRO N can significantly increase the energy yield throughout the lifetime of PV system. Firstly, more installed capacity of ASTRO N under the same installation area can increase the energy yield by about 4.5%; secondly, the longer working life of ASTRO N with power warranty of 30 years can increase the energy yield by about 19.4%~19.5%; thirdly, the advantages of lower LID and lower temperature coefficient can further increase the energy yield by about 3.9%~4.4%. Finally, the total energy yield of ASTRO N is up to 27.8%~28.4% higher than that of PERC modules in typical residential and C&I applications in different regions.

With the advantages of low BOS cost and high energy yield, ASTRO N can increase the internal rate of return (IRR) of the project by 0.36%~1.17% even at a premium of 1 cents/W over PERC.



In residential and C&I applications of different countries, the energy yield and IRR gain of ASTRO N compared with PERC modules when the premium of ASTRO N is 1 cents/W

6.3 BOS and LCOE - Utility Scale and Large C&I Applications

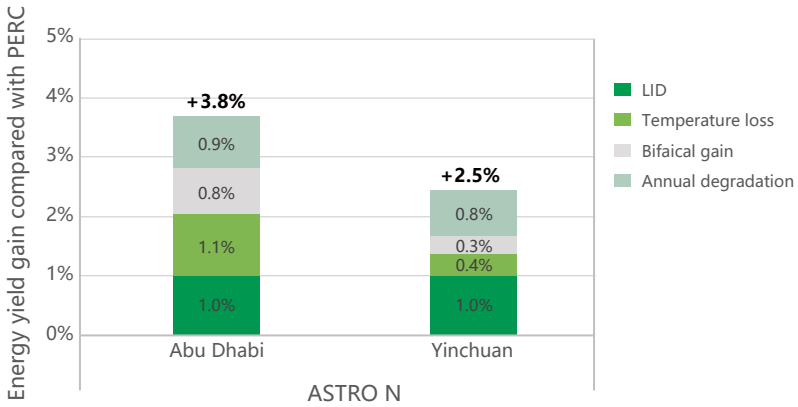
In the scenarios of utility scale and large C&I applications located in Abu Dhabi, United Arab Emirates with a typical dry-hot climate and Yinchuan, China with a mild climate and sufficient sunshine, the 100MW power plants are simulated construction with the 1P single-axis trackers, the 1500V centralized inverters and the DC/AC ratio of 1.2. The difference in energy yield and LCOE are compared between the ASTRO N5 575W modules and the same sized PERC 550W modules.

System Information		
Module type	**PERC-550W**	**ASTRO N5**
Module power(W)	550	575
AC capacity (MW)	100	
DC capacity (MW)	120	
GCR	0.33	
Mounting type	1P single-axis tracker	
Modules per string (pcs)	28/27	**28/27**
Annual degradation	0.45%	**0.40%**
Location	**Abu Dhabi/Yinchuan**	
Yearly average lowest ambient temp.	15℃/-8℃	
Albedo	0.20	
System voltage (V)	1500	
System lifetime	30 years	

Key parameters of the simulation design of large-scale power plants in Abu Dhabi and Yinchuan

Compared with PERC bifacial modules, Due to lower LID, lower annual power degradation, lower temperature coefficient to reduce high temperature loss and superior bifaciality, ASTRO N achieves the energy yield gain per watt of 3.8% and 2.5% in Abu Dhabi and Yinchuan, respectively.

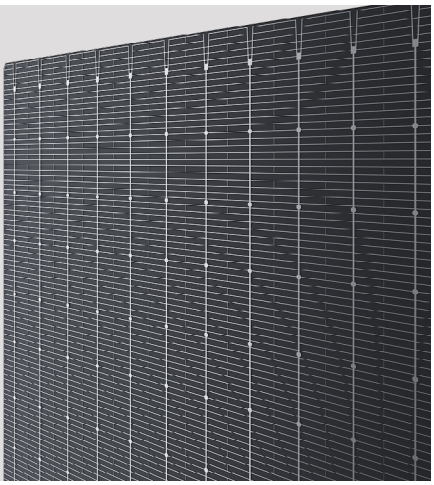
> **The advantage of high power generation of ASTRO N is more outstanding in high temperature regions such as the Middle East.**



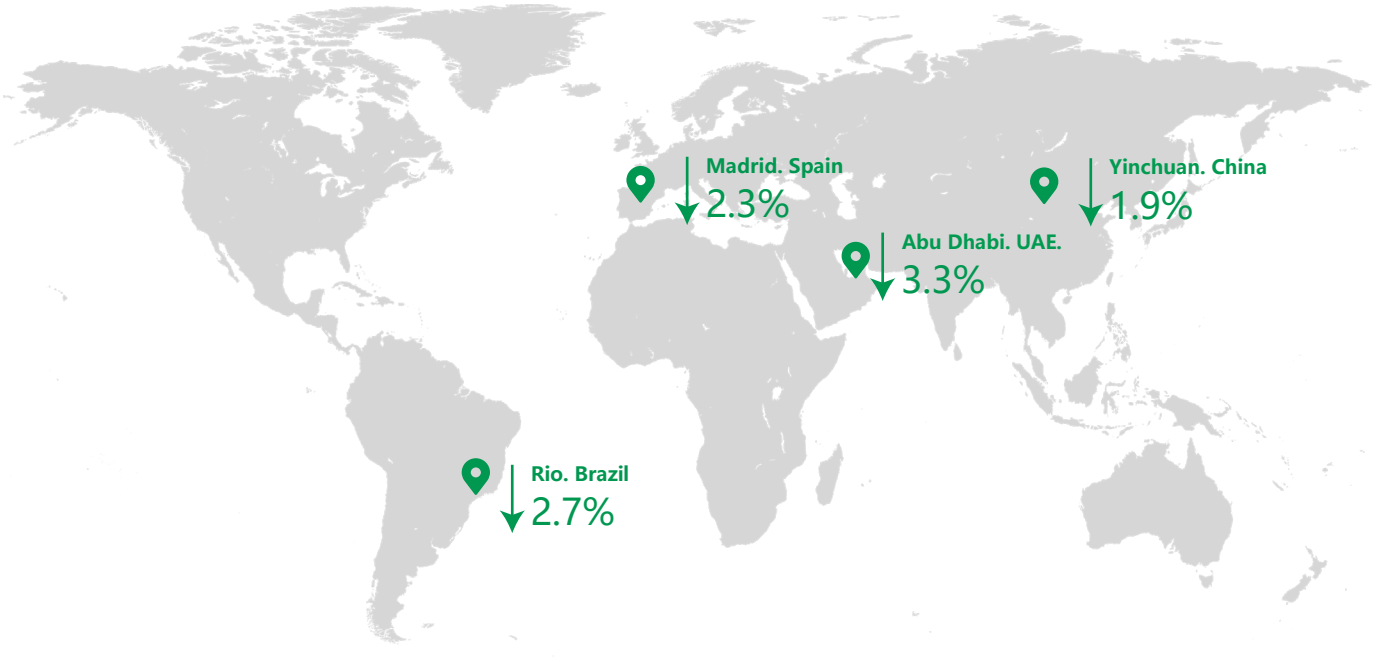
Energy yield gain per watt of ASTRO N compared with PERC bifacial module in different regions

The main ways to reduce LCOE are to reduce the initial investment and increase the total energy yield during the lifetime of a PV power station.

ASTRO N can not only effectively reduce the BOS cost, but also has excellent power generation performance. Therefore, the LCOE of PV power stations using ASTRO N will be significantly reduced.



As shown in the figure below, the LCOE of large-scale power plants in different regions using ASTRO N is 1.9%~3.3% lower than that using the same sized p-PERC modules even if ASTRO N is sold at a premium of 1 cents/W. If the prices of the modules are the same, the reduction of LCOE after using ASTRO N will be greater.

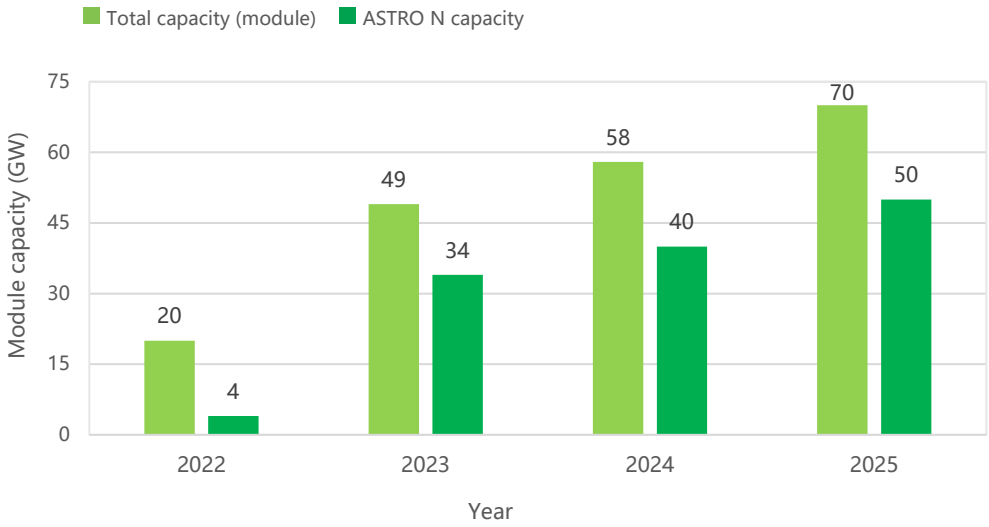


Based on a premium of ASTRO N5 of 1 cents/W, the LCOE decrements of power plants using ASTRO N5 compared with PERC bifacial module in different regions of the world (ASTRO N5-575W VS PERC-550W)

07 PART Future Prospect

At present, Astronergy has fully started the new track for n-type products, which can further meet the diverse demands of customers. ASTRO N has been widely recognized by the market for its excellent performance, and the whole series of products have successfully obtained the main certifications of TÜV Rheinland and UL.

By the end of 2022, the capacity of ASTRO N modules hit 4GW. During the 14th Five-Year Plan Period (2021-2025), Astronergy to expand its PV cell and PV module production capacity in high speed, and its module capacity is expected to reach over 70GW in 2025, which including over 50GW of ASTRO N modules.With the series products of ASTRO N, Astronergy can continuously provide the high-performance and high-quality PV products and the product solutions with lower LCOE to promote the development of clean energy and benefit the world!



Module capacity planning of Astronergy from 2022 to 2025