PV TECH POWER

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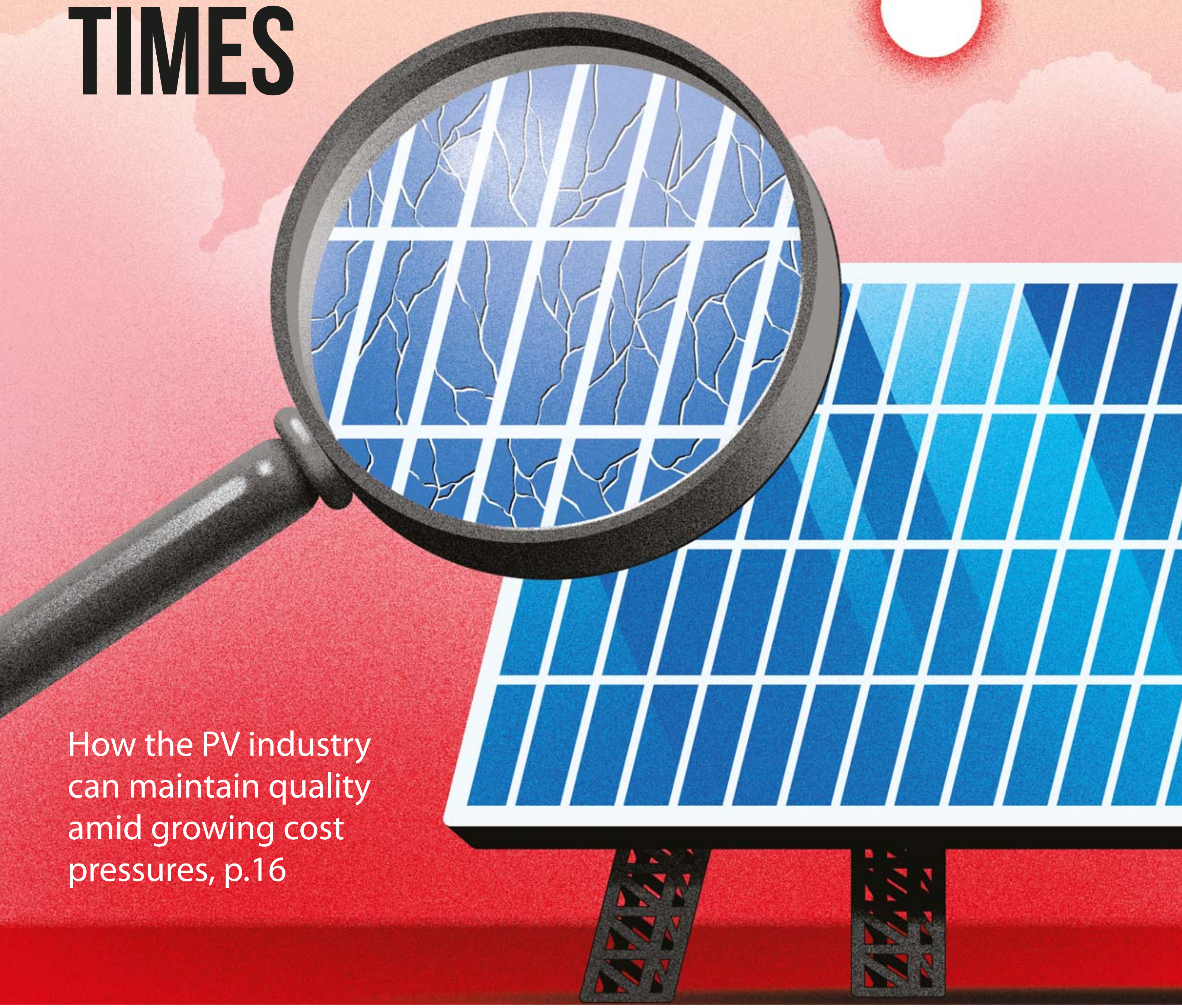
TESTING TIMES

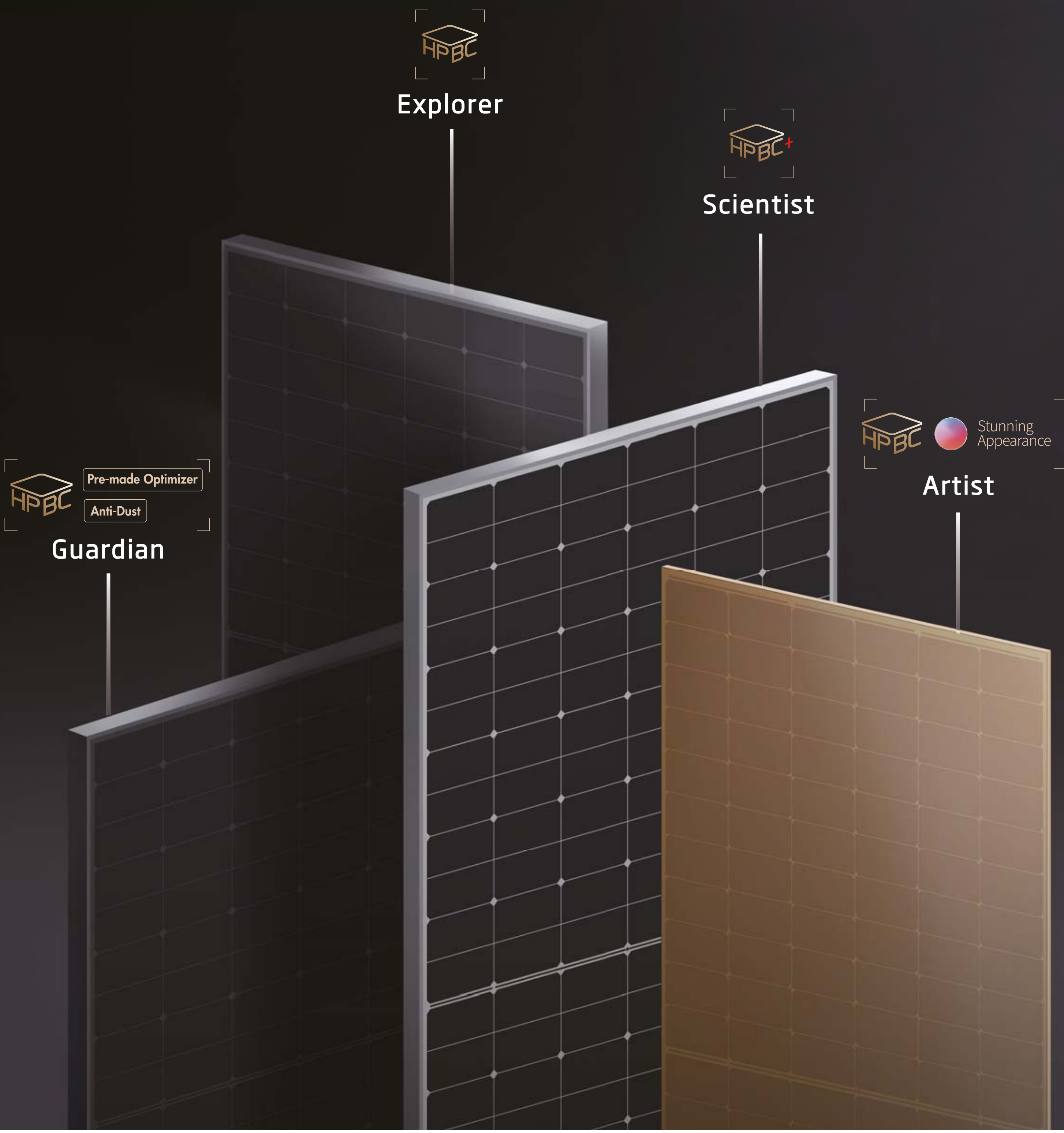


How the PV industry can maintain quality amid growing cost pressures, p.16

In association with Energy Storage News

Hi-MO X6

Illuminating Possibilities



PV TECH POWER

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Introduction

When the first edition of this journal was published ten years ago, the PV industry had witnessed its first major growth spurt. This was partly the consequence of China having taken over from Europe as PV module supplier to the world and, in the process, helped dramatically reduce module costs. But the industry was a victim of its success, and with the gold rush came oversupply, prompting savage cost-cutting as manufacturers did what they could to survive.

If this sounds familiar, it's because similar circumstances prevail today. Several years of aggressive capacity expansions, particularly by Chinese manufacturers, have led to overproduction and a severe inventory buildup. All the signs point to a downturn this year and, no doubt, a similar response by companies as they seek to remain in business.

A decade ago, one of the consequences of the solar industry's response to the downturn was a reported drop in module quality standards. "Reported" because, unsurprisingly, hard data on the extent of the problem was difficult to come by. But there was enough anecdotal and real-world evidence to warrant a closer look, and the first edition of *PV Tech Power* led with an investigation into the extent and nature of a problem that numerous industry observers told us was worse than immediately apparent.

With history to some extent repeating itself, we have decided to revisit the issue and ask whether a looming downturn means quality is once again on the line. It's a question already posed by our analyst colleague, Finlay Colville, whose research first brought the issue of a pending downturn to public attention. Our coverage is split across three separate articles. Reporter Will Norman speaks to several figures on the frontline of module quality assurance about how the industry can maintain quality in a period of huge cost pressures (p.16). Testing house PI Berlin looks at the industry's historical quality trends and assesses how it can manage future risks (p.20). And the head of TÜV Rheinland's solar segment explains how quality assurance practices are keeping up with the rapid pace of technological change in the PV industry (p.24).

Elsewhere in the journal, US-based insurer kWh Analytics investigates risk mitigation in the construction and operation of floating PV, one of the industry's fastest-growing segments (p.58). We also have a double bill of articles exploring how the solar industry needs to gear up for carbon pricing policies set to be introduced in the coming years in the EU and US (pages 74 & 78). In our Market Watch section, Lena Dias Martins offers some fascinating insights into how, despite its horrific ongoing war with Russia, Ukraine is still managing to build large-scale solar plants (p.32). And on p.42 Fraunhofer ISE's Michael Geiss reports on how the research institute's recent ground-breaking work on inverter architecture may help pave the way for a transition to higher voltages.

To round the journal off, our regular Storage & Smart Power section, brought to you by the team on our sister website *Energy-storage.news*, has analysis from Clean Energy Associates on recent pricing trends in battery energy storage systems (p.90).

As always, we hope you find this edition enjoyable and insightful. Thanks to all of you for your support over the first decade of this journal's existence. We look forward to charting the industry's development for many years to come.

Ben Willis
Editor
PV Tech Power

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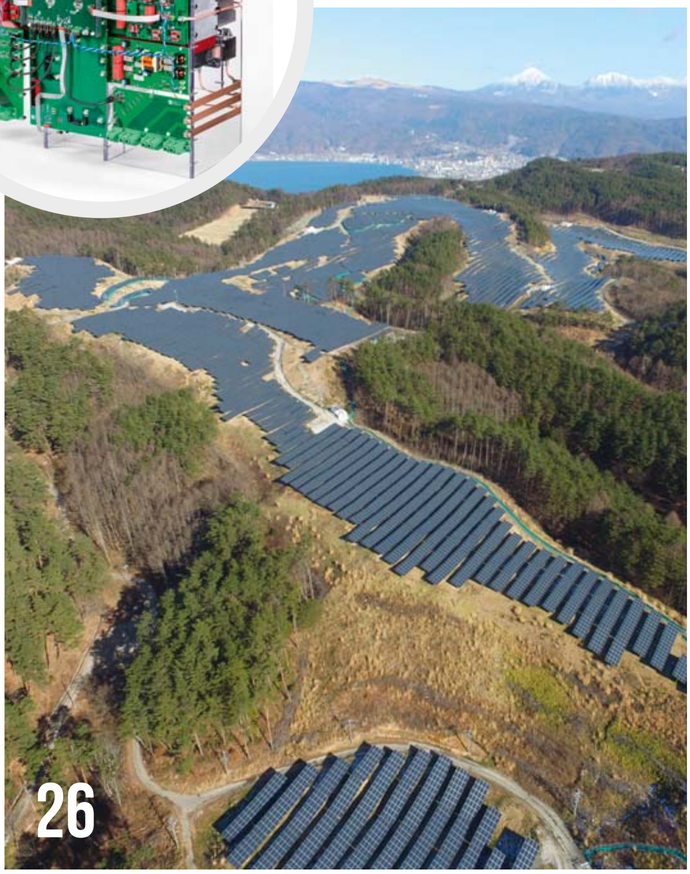


HUAWEI

FusionSolar

FusionSolar Residential Smart PV Solution

A Home that Always Shines

Shine on Active Safety I Shine on Full Journey Convenience I Shine on Energy-using Prospect


66
release
BY SCATEC


82


90


94


TW SOLAR
FORTUNE GLOBAL 500
Tongwei Gene
Repower N
G12R Series
New Generation Large Rectangle Products
Up to
455W
Module power
Up to
22.8%
Module efficiency
Up to
625W
Module power
Up to
23.1%
Module efficiency
Tongwei Solar
en.tongwei.com.cn

Tongwei Solar leads the way to a cleaner energy system with its G12R N-type module series

In 2023, installed solar capacity in Europe increased by 39% (66GW). The world's first PV industry member of the Fortune global 500, Tongwei Solar is committed to providing clients with the highest quality, most reliable products on the market. In 2022, the company shipped 3GW, or 14% of the residential market, to Europe, where almost one in seven households deploying PV modules was equipped with its Terra series product and, in late 2023, it took the significant step of launching its new G12R TNC series module.

N-type in the mainstream

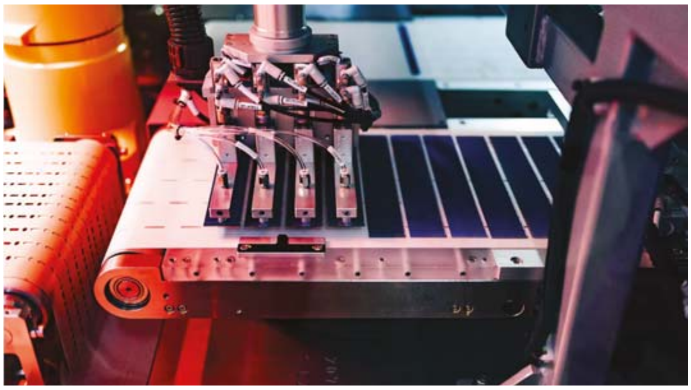
According to PV InfoLink forecasts, last year's rapid growth in TOPCon production will continue in 2024, fully surpassing PERC during the first half of the year. With a market share exceeding 60%, N-type products will be an absolute mainstream part of the PV market.

Introducing the G12R– Tongwei Solar's flagship N-type module series

Tongwei Solar's new generation G12R N-type module series has managed to strike the perfect balance between technological innovation, product efficiency, size, appearance and convenience of installation and transportation, already making it a preferred choice in the European market.

The G12R series silicon wafers, at 2382x1134mm, are considered the gold standard for rectangular design and boast new cell technology that is both self-developed and self-produced. Tongwei independently developed the industry's first pilot test line of 210mm PECVD Poly with an average cell production efficiency of 26.7%, with the G12R series incorporating the company's highly efficient, super reliable TNC technology for superior output.

The G12R series is testament to the company's constant efforts to produce superior value for any scenario. Leveraging the technology and efficiency advantages of large rectangular wafers, the modules deliver



greater value to clients with significantly increased power output, reduced costs and enhanced system yields, providing solutions for all residential, commercial and industrial (C&I) and utility-scale power plant scenarios – covering every possible client need.

Product advantages

At a system level, the G12R series offers a range of advantages:

- **Lower operating temperatures.** Using half-cell technology, the temperature range is 2-3 degrees Celsius lower and power output is increased by more than 0.5%.
- **Higher conversion efficiency.** The conversion efficiency of the modules is 23.0% or above.
- **Higher bifaciality.** TNC high-efficiency modules have a higher bifaciality at 80±5%.
- **Excellent load capacity.** The modules have passed 2,400Pa wind load and 5,400Pa snow loading tests.
- **Excellent PID resistance.** Optimised technology and materials minimise PID degradation.
- **Excellent low-light performance.** TNC high-efficiency modules can generate more power under low light conditions.

A top-tier player throughout the whole industry chain

Tongwei Solar employs integrated vertical strategies throughout the entire industry chain, from high-quality raw materials and research and development in cutting-edge technology to high-efficiency modules to ensure the upstream is equipped with the highest quality production capacity possible. This ongoing commitment to improving quality and reducing costs has brought the company to the top in silicon material and cell production. In 2023, it undertook an unprecedented increase in production capacity in its polysilicon, cell and module divisions. With module production output of 63GW in 2023 and plans to ramp to 100GW, the company is squarely positioned among the top tier of module manufacturers. According to PV InfoLink, global shipments of Tongwei

cells in 2023 once again ranked it in first place and, with module shipments also performing strongly to break into the top five, the company's overall branding received a significant boost.

Industry-leading ESG driving forward the green transition

ESG (environmental, social, and governance) is an important part of the green transition and sustainable development worldwide, and Tongwei Solar has a strong commitment to a leadership role in this area. By introducing green, low-carbon management to its entire product lifecycle, the company has succeeded in incorporating green concepts into its entire industry chain, saving on energy and reducing carbon emissions, its initiatives leading to recognition in the 2023 Fortune China ESG Impact List with an A level Wind ESG rating.

In terms of environmental practices, Tongwei Solar was the first company in the world to create a Fishery & PV Integration green development model to generate a continuous stream of clean energy. As of the end of 2022, it had established 52 PV power stations in China according to this model for a cumulative installed, grid-connected capacity of 3.4GW, an annual settlement volume of 4.06 billion kilowatt-hours and total carbon emission reductions of 3.09 million tons. The optimised design of the G12R series has also maximised the container utilisation rate at 98.5%, reducing transportation costs by 4% and increasing land utilisation by 8.73% compared to 182-type modules, ensuring higher returns.

As a socially responsible organisation, Tongwei is mindful of the critical importance of the global energy transformation mission, and a diverse product portfolio and comprehensive technical reserves provide international clients with more options, ensuring development achievements benefit everyone.

In terms of governance, the company strictly adheres to established industry standards and codes of practice, providing global clients with the best possible quality and most cost-effective solutions. The six major pillars of the G12R series consist of material selection and control, production process management, multiple environmental testing certifications, quality system processes, shipment quality inspection and professional client services that include high-quality after-sales care.

ESG and sustainable development are sweeping the globe, with PV power generation critical to both the green energy transition and the achievement of zero carbon emissions. Tongwei Solar's G12R series is destined to make an important contribution to the worldwide adoption of clean energy.

More information: **en.tongwei.com.cn**

EUROPE

Germany

Enerparc secures financing for 325MW solar-plus-storage portfolio in Germany

German engineering, procurement and construction (EPC) firm Enerparc has secured bridge financing for a 325MW solar portfolio in Germany, which will include co-located battery storage projects. The funding was provided by the Eiffel Investment Group, a French investment firm, and while the companies did not specify the amount of money provided, Enerparc noted that the funds would go towards projects that have either finished construction or will be commissioned "soon". The portfolio consists of 15 projects, the smallest of which has a capacity of 6MWp, while the largest has a capacity of 39MWp. "With the successful completion of this transaction, we have finalised the financing for an extensive portfolio," said Marco Langone, head of finance at Enerparc. "Most importantly, we have expanded our network of financing partners by adding a new partner from the debt fund sector."

Image: Enerparc

Enerparc plans to build a 325MW solar portfolio in Germany with co-located storage projects.

BloombergNEF: Europe drives global corporate PPA growth in 2023

Global corporate power purchase agreement (PPA) volumes for solar and wind increased to a record of 46GW in 2023 driven by substantial growth in Europe, the Middle East and Africa (EMEA), according to BloombergNEF's (BNEF) latest study. In its '1H 2024 Corporate Energy Market Outlook', global PPA volumes increased from 41GW in 2022 to 46GW in 2023, representing a 12.2% increase. Of the global volumes, the US, Canada and Latin America (AMER) market accounted for 20.9GW (about 45%), down from 24.4GW in 2022. The US remained the largest market for PPAs with 17.3GW of deals announced, down 16% from the record 20.6GW announced in 2022. The report said the economics for signing PPAs were far weaker in the US as developers were locked into expensive equipment contracts signed in prior years during supply chain bottlenecks, in addition to high interest rates.

RWE and PPC to build 450MW solar project in Greece, expand portfolio to 940MW

German energy company RWE and Greek renewables developer PPC will build a new 450MWp solar project in Greece, which will bring the total capacity of the companies' portfolio in the country up to 940MWp. The firms will build the project through a joint venture company, Meton Energy SA, and this represents the last phase of construction in the group's Amynteo portfolio in Western Macedonia. The companies announced plans to develop the portfolio further last August, and expect to begin construction at this final project, dubbed Orycheio Dei Amynteo, in the next few months, and commission the project in 2025. As part of the deal, Meton has signed a power purchase agreement (PPA) with both RWE and PPC to acquire power generated at the new project, and RWE announced that the companies will invest US$274.9 million (€255.4 million) into the new development, of which US$137.5 million (€127.7 million) was given through the EU's NextGenerationEU fund.

Enphase quarterly revenues fall by circa US$250 million

US microinverter supplier Enphase Energy has published its financial results for the fourth quarter of 2023, which includes a total revenue of US$302.5 million in the quarter, and revenue of US$2.3 billion in the 2023 financial year. The company's revenue has fallen for a third consecutive quarter, from US$711 million in the second quarter of 2023 to US$551.1 million in the third quarter of the year, but its gross margin has improved, increasing from 47.5% to 48.5% between the third and fourth quarters of 2023. Enphase's operating income and net income have also fallen, from US$118 million to a loss of US$10.2 million, and US$114 million to US$20.9 million, respectively. Enphase suggested that a decline in equipment sales in Europe contributed to this decline, with a 70% fall in the company's European revenue between the third and fourth quarters of 2023.

Solar to lead EU power generation growth in 2024

Europe's solar power generation is expected to increase by 50TWh this year thanks to increased capacity installations on the continent with Germany leading the growth, according to research firm Rystad Energy. This year, Europe's power generation will grow to 2,740TWh, up from 2,687TWh in 2023. Solar will lead the growth, followed by wind (38TWh), nuclear (20TWh) and hydro (6TWh). On the contrary, power generation from fossil fuels will continue to decrease but at a much slower rate compared to 2023. The generation of power from fossil fuels will decrease by 60TWh due to a slight increase in overall power demand in Europe during the same period. As solar is expected to continue leading the growth in terms of capacity and generation, coupled with more stable output from nuclear generation, Rystad Energy said there will be a further decline in fossil fuel demand for power.

AMERICAS

NREL estimates 1TW of potential US community solar

The US has the potential to add nearly 1TW of community solar capacity if all technically viable community solar is deployed, according to the National Renewable Energy Laboratory (NREL). In a recent report, called 'Technical Potential and Meaningful Benefits of Community Solar in the United States', NREL estimated technical potential for community solar capacity deployment with two different regimes, one dubbed Limited Access, with 967GWac, while the Reference Access more than trebles that number with 2.9TWac. The resource area for ground-mount community solar systems ranges from nearly 12,000 to 53,000 km2, which is in addition to resource areas considered for utility-scale renewables in urban and suburban areas where only smaller systems can be deployed and are not located on federally owned lands.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Investment

Rystad Energy: world needs to invest $3.1 trillion into grid infrastructure by 2030

Figures from US research firm Rystad Energy suggest that the world will need to invest US$3.1 trillion into electricity grid infrastructure before 2030, if the world is to limit global warming to 1.8 degrees Celsius by 2050. This investment would dramatically expand the world's electricity grids, adding 18 million kilometres of grid connections, and requiring the use of close to 30 million tonnes of copper. The clean energy transition is increasingly facing a challenge when it comes to grid capacity, as the rapid construction of new renewable power plants often exceeds grids' capacity to take power from these projects. Last year, think tank Ember noted that, in Europe alone, grid connectivity will need to double over the next 15 years in order to reach the continent's climate change goals, and analysts at Rystad agree with this assessment.

Image: Andrey Metelev via Unsplash

The world will need to add 18 million kilometres of grid connections by 2030

Rooftop solar generation meets 1.5% of US electricity demand in 2022

Production of small-scale solar installations increased by ten times between 2012 and 2022, but the US has only tapped into a small fraction of the technical potential of rooftop solar, the major contributor towards small-scale solar installations. According to the report 'Rooftop solar on the rise', compiled by the Frontier Group and the Environment America Research & Policy Center, small-scale solar generation grew rapidly from 5,959GWh in 2012 to 61,281GWh in 2022, driven by the rapid uptake of installations on homes. In 2022, residential solar systems generated 39,510GWh, or 64% of all electricity from small-scale solar installations in the US, while commercial produced a total of 17,724GWh.

Super Bowl LVIII powered entirely by Nevada solar-plus-storage project

Super Bowl LVIII was powered entirely by renewable power, with an EDF Renewables solar-plus-storage project in Nevada meeting the energy demands of the final game of the 2023 NFL season. The game, which took place on 11 February, 2024, at Allegiant Stadium in Las Vegas, Nevada, required 28MWh of electricity, according to climate tracker NZero, which was provided by EDF's Arrow Canyon project. The solar-plus-storage project has a power generation capacity of 275MW, alongside a 5-hour battery energy storage (BESS) facility with a capacity of 75MW, which reached commercial operation last November. The project uses bifacial panels from manufacturer Canadian Solar, and a BESS delivered by a "tier one energy storage system supplier", although EDF Renewables did not name a company involved in the manufacture and delivery of the battery systems. Super Bowl image. Caption: Allegiant Stadium hosted the first NFL game to be exclusively powered by solar power in October 2023.

Ingeteam to supply inverters to Grenergy's 1GW solar-plus-storage project in Chile

Spanish independent power producer Grenergy has chosen Spain-based energy conversion equipment specialist Ingeteam as its technology partner for a 1GW solar-plus-storage project in Chile. Ingeteam will provide solar and storage inverters pre-integrated into the transformer stations and delivered as a turnkey solution ready for installation. Ingeteam will also supply the control system and commissioning services for the inverters, transformer stations and facilities. Located in the Chilean Atacama desert, the Oasis de Atacama project, which has the largest capacity of any storage project in the world, will be built in five phases and is expected to be fully operational in 2026 with an installed solar capacity of 1GW and 4.1GWh of storage capacity. Last month, Grenergy signed a power purchase agreement (PPA) for the fourth phase of the project, which will see the company add 260MW of new solar and 1.1GWh of new storage capacity.

MIDDLE EAST & AFRICA

Solar-storage hybrid to power Sierra Leone gold mine

Renewable energy financing platform CrossBoundary Energy will develop a hybrid solar PV, battery energy storage system (BESS) and thermal energy project at the Baomahun gold mine in Sierra Leone. In a partnership with old mining company, FG Gold, the project will supply around 90% of the mine's energy demand during daylight hours. CrossBoundary said that the site will be Sierra Leone's first large-scale commercial gold mining project and could become a model for sustainable mining operations". CrossBoundary will finance the development and construction of the project, which will feature 23.8MW of solar PV, 13.8MWh/13MW BESS and a 21MW thermal plant. Construction is expected to begin in Q4 2024.

Larsen & Toubro to build 1.8GWac project in Dubai's mega solar park

Indian conglomerate Larsen & Toubro has been contracted to build a 1.8GWac solar PV project as part of Dubai's Mohammed bin Rashid Al Maktoum Solar Park. The renewables arm of Larsen & Toubro's Power Transmission & Distribution business was chosen as the turnkey engineering, procurement and construction (EPC) contrac-

Saudi Arabia

Saudi Arabia announces successful bidders for 3.7GW solar projects

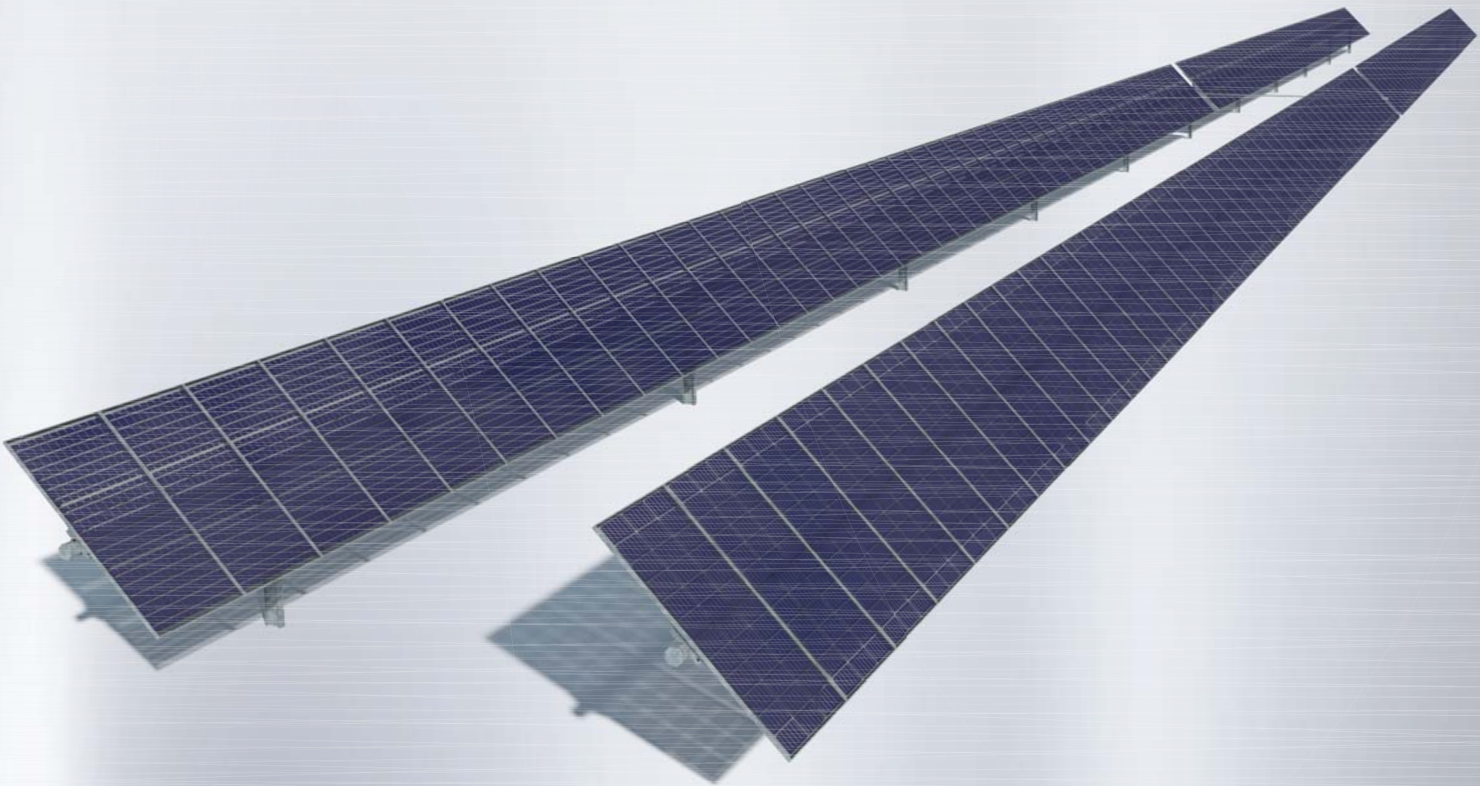
The Saudi Power Procurement Company (SPPC) has unveiled the qualified bidders for the fifth round of 3.7GW solar projects under the National Renewable Energy Programme (NREP) in Saudi Arabia, including several major renewables developers. In an announcement published by the Saudi Press Agency, the SPPC announced that Masdar, EDF Renouvelables, Itochu Corporation, Total Energies Renewables, and Saudi Electricity Company were among the companies that won bids. The biggest project offered in this round is Al Sadawi with a capacity of 2GWac, located in the Eastern province of Saudi Arabia. The 1GWac Al Masa'a project will be located in the Hail province, while two more solar projects, including the 400MWac Al Henakiyah 2 project and the 300MWac Rabigh 2 project, will be built in the Madinah province and the Makkah province respectively.

AXONEDUO INFINITY

WITNESS THE EXTRAORDINARY

AxoneDuo Infinity redefines solar power generation. Its innovative technology offers unprecedented adaptability and reliability, accommodating a variety of configurations to meet the specific requirements of any site. With state-of-the-art defense mechanisms against adverse weather conditions, **AxoneDuo Infinity** maximizes the potential of PV modules while minimizing costs and environmental impact.

- DELIVERED PRE ASSEMBLED
- ALLOWS MULTIPLE CONFIGURATIONS. LINKED OR UNLINKED ROWS, 2, 3 OR 4 STRINGS PER ROW
- MINIMUM NUMBER OF MAN HOURS ON SITE
- LOWEST NUMBER OF MOTORS AND CONTROLLERS PER STRING IN THE MARKET
- IMPROVED TERRAIN ADAPTABILITY
- 75º HAIL OPTION



PVH

tor. The scope of work will include building the solar PV project, the interconnection of two gas insulated substations, and the installation of high-voltage underground cables and medium-voltage power distribution networks. The solar PV project will be the sixth phase of the 5GW Mohammed bin Rashid Al Maktoum Solar Park and become operational in three phases.

EDF Renewables closes financing on 500MW solar plant in Oman with Korean partner

A consortium of EDF Renewables and Korea Western Power Corporation (KOWEPO) has reached financial close on a 500MW solar PV plant in Oman. The Manah 1 project, located in the Al Dakhiliyah Governorate, is under a 20-year power purchase agreement (PPA) with Oman Power and Water Procurement Company (PWP). Operations are expected in the first quarter of 2025. Over one million bifacial PV modules will be deployed at the site on single-axis trackers. Financing was secured from French, Korean and Omani lenders the Export-Import Bank of Korea, European bank Société Générale and Oman Bank Muscat through equity and loan schemes. The consortium did not disclose the sum of the financing.

Kuwait launches request for qualification for 1.1GW of PV

The government of Kuwait has launched a tender for solar projects with a total capacity of 1.1GW, to be installed at its Al Shagaya Renewable Energy facility in the west of Kuwait City. The Kuwait Authority for Partnership Projects (KAPP) and the country's Ministry of Electricity & Water & Renewable Energy launched the request for qualification this week, the third phase of development at the Al Shagaya facility. While the government bodies did not specify whether the tender would take the form of a single large project, or be open to multiple smaller projects with a number of investors, they noted that successful projects would enter into a 30-year power purchase agreement with the ministry to acquire electricity produced at the project.

South Africa opens seventh bidding window of REIPPPP, seeks 1.8GW solar PV

Norwegian independent power producer (IPP) Scatec has commissioned a 540MW solar-plus-storage project in South Africa. Located in the Northern Cape province, the Kenhardt project consists of three solar plants and a battery energy storage system (BESS) with a capacity of 225MW/1,140MWh. Under a 20-year power purchase agreement (PPA) with state-operated utility Eskom, the project will deliver 150MW of power to the national grid between 5am and 9:30pm. The project had an investment of nearly US$1 billion and was Scatec's largest project commitment, with the debt provided by a group of lenders which includes the Standard Bank Group, acting as lead arranger, and British International Investment.

ASIA-PACIFIC

Vena Energy and Amazon bring 125MW Queensland solar project online

Renewable energy independent power producer (IPP) Vena Energy began operations at a 125MW PV site in the Australian state of Queensland last week, through a partnership with US technology giant Amazon. The 125MW Amazon Solar Project Australia – Wandoan forms part of the larger Wandoan South Project, a renewable energy project with a total 650MW/450MW solar PV and battery energy storage capacity, owned by Vena Energy. The project has deployed over 250,000 solar modules and will support Amazon's operations in Australia. "Amazon is on a path to power our operations with 100% renewable energy by 2025," said Ken Haig, head of energy and environment policy, Asia Pacific & Japan, Amazon Web Services. Amazon has become a very large player in the renewable energy market; it added over 1GW of solar and wind power operations to its portfolio in Europe alone last year.

GCL System Integration guides revenues to double in 2023 as n-type ramp up continues

Chinese module manufacturer GCL System Integration (GCL SI) has released preliminary results for its fiscal year ended in 2023 with revenue increasing between 85.6%-109% year-on-year as it continues ramping up its n-type module and solar cell capacity. During the reporting period, the company continued to expand its production of n-type solar cells and modules, with the first phase of its module assembly plant in Hefei reaching full capacity and with 15GW of annual capacity. Once all phases are completed, the Hefei plant will have a 60GW nameplate of annual capacity, while the Funing module assembly plant reached its targeted annual capacity of 12GW high-efficiency modules. GCL SI is also expanding its cell capacity with the first phase of the 20GW Wuhu cell plant becoming operational in October 2023 and with 10GW of n-type cell annual capacity, for which the company expects to raise up to RMB4.8 billion (US$672 million) to fund the plant.

Recycling

Qcells inks recycling agreement with Solarcycle for US-made modules

12 February. Korean-owned solar manufacturer Qcells has signed an agreement with Texas-based solar module recycling firm Solarcycle to recycle Qcells' decommissioned modules in the US. The agreement will cover Qcells' "decommissioned, owned and installed solar panels in the United States", and materials recovered from these modules will be reused in the domestic US solar supply chain, Solarcycle said in a press release. Qcells is establishing a US$2.5 billion, 8.4GW solar module production expansion in Georgia across two facilities, and has also said that it will produce solar ingots, wafers and cells in the state. The company said that its operations constitute the "largest silicon-based solar panel factory in the US", exceeded only by Ohio-based First Solar's production of Cadmium Telluride thin-film modules. "We are proud of the clean energy products we offer, but Qcells is committed to going further than that," said Kelly Weger, Qcells' director of sustainability.

Image: Qcells.

Qcells plans to expand its influence in the US with two new module production facilities

India proposes roof top solar incentives in interim budget for 2024-25

The Indian government has announced incentives for rooftop solar in its Interim Budget 2024-2025, offering ten million households the opportunity to obtain free solar electricity every month. Indian finance minister Nirmala Sitharaman proposed that free 300kWh of electricity will be provided to ten million households in India every month under the rooftop solar plan. Under the plan, the beneficiaries can save up to INR18,000 (US$216.7) from free electricity and selling the surplus to the distribution companies. In addition to rooftop solar, the Indian government also allocated INR8,500 crores (US$1.1 billion) to the country's grid sector for the fiscal year 2024-2025, up from INR4,970 crores (US$663.5 million) in the previous fiscal year. For the upcoming financial year, the Indian government increased its allocation of resources to the Ministry of New and Renewable Energy (MNRE) by 25.7%.

Huasun to supply 1.2GW G12R rectangular heterojunction solar cells

Chinese solar manufacturer Huasun has finalised a deal to supply 1.2GW of G12R (210mm) rectangular heterojunction (HJT) solar cells to an undisclosed company. Under a cooperation agreement, Huasun will supply the solar cells, while both companies will collaborate in various areas, including research and development of HJT technology. This supply agreement also marks the first gigawatt-scale rectangular solar cells deal for HJT cells, according to the company. The Everest G12R rectangular HJT solar cells are built on a half-cell silicon wafer measuring 182mm*105mm, while implementing HJT3.0 bifacial microcrystalline mass production technology, advanced silver-coated copper and super multi-busbar (SMBB) processes. This integration allows for improved photoelectric conversion efficiency, which can read 35.5% for mass-produced cells. With the company focused on HJT technology – both in cells and modules – it shipped over 3GW of products in 2023, according to Yang Zongyuan, general manager of Huasun's sales division in China.

Efficiency record

Fraunhofer ISE, Oxford PV co-develop tandem PV module with 'record-breaking' efficiency

Perovskite solar cell researcher Oxford PV and German research organisation Fraunhofer Institution for Solar Energy Systems (Fraunhofer ISE) have developed a full-sized tandem PV module with a record efficiency of 25%. The glass-glass tandem PV module produced by Fraunhofer ISE boasts an efficiency rate of 25% – related to the designated illuminated area – and an output of 421W on an area of 1.68 square metres, which is the world's most efficient silicon perovskite tandem solar module in industrial format, according to Fraunhofer ISE. As the perovskite layer of the tandem cells is temperature-sensitive, the Fraunhofer ISE research team developed low-temperature processes for the interconnection and encapsulation of the solar cells.

Credit: Fraunhofer ISE/Bernd Schumacher

Oxford PV and Fraunhofer ISE claim a 25% efficiency with their full-sized tandem PV module

MANUFACTURING

REC Silicon to shut down polysilicon production capacity in Montana, US

Polysilicon manufacturer REC Silicon has decided to shut down its polysilicon production capacity at its Butte facility in Montana, US. The company's wholly-owned subsidiary, REC Advanced Silicon Materials LLC, will shut down the polysilicon production capacity due to increased electricity costs in the region both in the short and mid-term. Production will continue for six to nine months, in order to fulfil ongoing orders to customers. Even though the company will be shutting down the Butte polysilicon production, it will still be producing polysilicon at its Moses Lake facility in the northwestern state of Washington, which started its first production during the fourth quarter of 2023. For that facility, REC Silicon secured a 10-year fluidised bed reactor polysilicon supply agreement with South Korean conglomerate Hanwha Solutions last year, which is estimated at US$3 billion. The first deliveries from the Moses Lake facility are expected in Q1 2024, with a ramp up to 50% during Q2 2024 and reaching full capacity by year's end.

CubicPV scraps 10GW US wafer factory due to "dramatic collapse in prices"

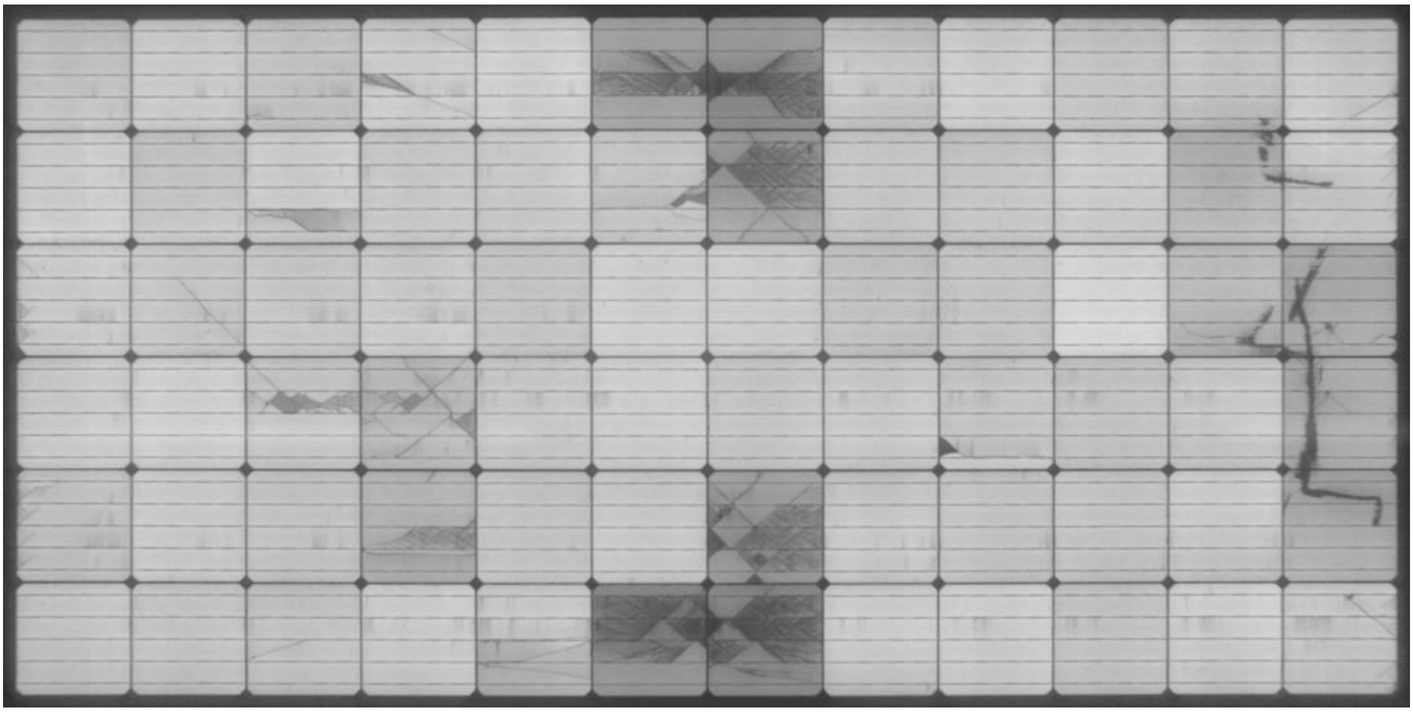
US solar manufacturer CubicPV has abandoned its plans for a 10GW solar wafer manufacturing facility in the US and is restructuring its business to focus on tandem technology module development. In a statement, CubicPV blamed market dynamics including a dramatic collapse in wafer prices and a surge in construction costs for its failure to realise a domestic manufacturing base. CubicPV first announced plans for the 10GW facility in December 2022, which it said would be developed alongside its work on silicon-perovskite tandem solar technology. Over the course of 2023 the company received a US$103 million equity financing deal to support the factory, announced an engineering partner and, most recently, inked a US$1 billion polysilicon supply deal with South Korean-owned producer OCIM. Additionally, jobs that were tied to the wafer production facility have been cut.

NexWafe expands to the US, aims 6GW of wafer capacity

Germany-based solar wafer producer NexWafe has expanded to the US and is exploring the possibility of building an initial development capacity of 6GW of solar wafers. NexWafe has not yet selected a location, and is currently assessing potential manufacturing locations, along with securing strategic partnerships and offtake agreements for domestic wafer supply. The operations in North America will use the company's EpiNex production technology, which aims to simplify polysilicon production and reduce energy consumption and production time. The process will be used at its production facility in Germany, which is currently under construction and will have an annual capacity of 250MW.

Testing times

Module quality | In the first edition of *PV Tech Power* ten years ago, our cover article looked at the issue of PV module quality, which had come to the fore after a period of heavy cost-cutting in the industry. Following a decade of technological innovation, the overwhelming dominance of Chinese manufacturers and a global explosion in solar capacity that has seen costs fall dramatically, we are revisiting the issue. Will Norman asks if the seeds for a looming quality problem have already been sown



Credit: 2DegreesKelvin

In conversation with *PV Tech Power,* John Davies – the CEO and founder of 2DegreesKelvin, a UK-based solar quality and testing consultancy – recounts a tale from his company's years testing solar modules for damage in the field. He remembers a recent instance of testing a roughly 50MW-scale site for a client that had bought two batches of modules, one of a lower power output class and one higher.

"We tested around 2,000 modules," Davies says. Around 13% of the higher-powered batch of modules were impacted by grid finger interruptions [a type of manufacturing soldering error], and they were operating at around 1% higher than the power output advertised on the box; "pretty much exactly where you'd expect it to be for brand new, fresh-out-the-packet modules," he says.

"In the lower power class, approximately 80% of the modules were affected by grid finger interruptions, and the power was approaching 8% down on flash tests," he continues.

The batches were both ordered from the same manufacturer and delivered to the same recipient, but the difference in the product quality was stark. Ultimately this case resulted in a successful warranty claim as the modules were newly delivered and evidently sub-par, but things are not often so straightforward.

Tracing the source

"I don't think we've ever received modules from the field where we didn't see some cell cracks," says Cherif Kedir, president and CEO of the Renewable Energy Test Centre (RETC) in Fremont, California. "Where they happen, how they happen and how long it takes to happen is quite debatable and everybody is pointing fingers at everybody else."

Cracking is among the most prevalent problems affecting PV modules

Alongside cell micro-cracks and grid finger interruptions, common defects in solar modules also include backsheet cracking, striation rings and soldering errors.

A report earlier this year from the Clean Energy Associates (CEA) in the US found a rise in solar PV module defects, most notably micro-cracking, line cracks and soldering errors, which it said came largely from the manufacturing side. While cracking can occur at almost any point during a solar module's life – from the factory to shipping, to unpacking, to installation to weather damage – the CEA's findings specifically highlighted a rise in manufacturing errors.

According to the CEA website, micro-cracks – which are invisible to the naked eye and only show up under electroluminescence (EL) testing – "have the potential to develop into a loss of active cell area and reduce the output of the entire string containing a defective module. Over time microcracks can lead to diode activation or

Site selection

It's important to mention that, beyond manufacturer or EPC errors, site selection and extreme weather can play a role in module damage and could influence figures showing an increase in issues.

According to a report from insurer GCube, memorably titled 'Hail No! Defending solar from nature's cold assault', the average claim for damage incurred by solar projects from hail has been almost US$58.4 million per claim in the last five years. NASA says that Earth's changing climate since the Industrial Revolution has caused an increase in "extreme" weather events like heat waves, floods and severe hail.

Volume 37 of this publication last year covered the way that solar PV is adapting to worsening weather conditions. However, in our conversation, Kedir says that site selection itself, in relation to extreme weather, can play just as significant a role in quality.

"Something I do know, which is maybe more fundamental [than generally more extreme weather], is that modules are being installed in really crappy areas, in places where humans do not want to live because you're going to have these huge boulders falling out of the sky and you don't want them to decimate your house and your car or kill your kids.

"And so," he continues, "these tend to be areas where land is very cheap, where developers can put modules. That's a really bad combination." He says that many installations are happening in areas where they probably shouldn't be, either because of the price of land or the distance from communities or both, and that this could factor into the apparent rise in defects reported by the CEA.

On-site testing. Site selection could influence figures showing an increase in module performance issues

Credit: 2DegreesKelvin

hot spots that represent a safety risk."

Wherever they come from, damage and cracking cause loss of power and return on investment for an asset owner, but also introduce an element of instability to a large-scale, high-voltage piece of infrastructure.

Cherif Kedir says that data on where a defect has occurred in the chain from manufacturing to O&M is almost impossible to come by.

"The data stops when the module manufacturers put the modules inside the crates. There are some efforts right now by developers to perform field EL testing on the modules before they're installed, but it's not something that is sustainable or cost-efficient. It's pretty cost-prohibitive to perform EL testing on millions or hundreds of thousands of panels, it just doesn't make sense. Especially when the cost of PV is so low."

Kedir says that some developers are testing samples of their module shipments to check for defects straight out of the box, searching for systematic problems across a considerable percentage of the test sample. This is the sort of process that Davies and 2DegreesKelvin engage in and can – sometimes – result in effective warranty claims to manufacturers or EPCs.

In Kedir's estimation, buyers test straight out of the box so they can turn to the manufacturer and point to issues rooted there. Manufacturers can't blame shipping, as the containers that modules are shipped in often come from the manufacturers themselves.

But issues that arise later or more obscurely can cause issues with the EPC, Kedir explains. Either the EPC has caused damage to the modules, which passes responsibility to them, or they've degraded too quickly, which throws the ball back to the manufacturer. "So you still have issues between manufacturer and EPC agreeing over whose responsibility it is," he says.

"Without doubt, with the decline in module prices, there will be continued pressure on quality and thus higher risks for PV project developers"

In response to questions from *PV Tech Power,* George Touloupas, senior director, technology and quality at the CEA said: "Buyers must be very diligent with vetting suppliers, products and manufacturing facilities by engaging third parties to perform due diligence and audits before production starts. During production, before shipment, and even post-shipment, it is imperative to have the necessary oversight, inspections and testing to ensure quality and accountability."

Third-party testing organisations, such as Fraunhofer ISE, TÜV Rheinland and RETC, can test modules either at the factory or installation stage, as well as auditing EPCs and manufacturers themselves. But, as Kedir points out above, testing thousands of increasingly cheap panels, or taking the time and effort to insist on supply or EPC auditing, takes financing and coordination that not all parties are willing to commit.

An echo of the past? The prospect of a downturn

The spiritual companion piece to this feature, published in the first PV Tech Power a decade ago, opened with a report which found hundreds of thousands of modules made by the now-defunct Netherlands manufacturer Scheuten Solar to be a fire hazard. This sort of drama seems to mostly have been ironed out in the last 10 years as manufacturers have consolidated, expanded and honed their operations, and the big Chinese players have come to dominate the market.

There is, however, a convergence of dynamics and predictions in the solar market that has the potential to cause concern for the quality of solar modules being put on the ground.

Foremost among these is the falling price of modules over the last year. October 2023 saw the first time that bidding prices for modules in China fell below RMB1 per watt – roughly US$0.014 at the time of writing. PV Tech's head of research, Finlay Colville, published a blog post in November predicting that the low price of modules would continue, putting pressure on large manufacturers to remain in the black and turn a profit on the huge capacity expansions they've invested in over the last decade. These pressures could lead to a downturn in fortunes for major manufacturers.

From low prices it follows that, faced with the need to manage the cost of production, manufacturers may be pushed to cut corners. Colville tells *PV Tech Power*:

"At this point, we just don't know what cost-cutting measures are going to be deployed in China or by Chinese manufacturers with capacity in Southeast Asia."

Cherif Kedir says, more wryly: "A developer told me that he felt that the price of modules was so low he was waiting for the day modules were going to be sold by the pound rather than by power."

Low prices are already having an impact. In recent months, the European solar manufacturing industry has been lobbying for emergency support from the EU as major players REC Group and Meyer Burger have pulled out of significant operations on the continent. The reason is twofold: oversupply and alleged price dumping, which have made it extremely difficult for EU manufacturers to continue – let alone set up – operations. Reportedly there are multiple gigawatts of surplus modules in and around the port of Rotterdam, modules which the European Solar Manufacturing Council (ESMC) says are being produced at uncompetitively low cost, sometimes below the operating costs of the manufacturers themselves.

This is an extreme result of low pricing and, possibly, a failure in governance, but it spells out the impacts that cost pressure can have on the manufacturing process. Niclas Weimar, chief technology officer at European testing firm Sinovoltaics tells *PV Tech Power* that this price pressure can have a direct impact on quality assurance.

"Without doubt, with the decline in module prices, there will be continued pressure on quality and thus higher risks for PV project developers," Weimar says. "With hundreds over hundreds of PV module factories in the world with largely similar product portfolios and thus limited USPs, pricing remains one of – if not, the key – selling point in the fiercely competitive manufacturing business where corner cutting and minuscule savings on quality procedures can have a significant revenue impact.

"There are ways for factories to potentially cut costs, whether it's on the resources for comprehensive quality management or on raw materials and their related logistics. However, such cuts come with significant quality risks."

Colville adds: "Some of the cost of the module can be taken out simply by passing the 'pain' of a low pricing environment back onto your suppliers: but this only gets you so far. Making changes to the materials themselves that are used in production will have to be considered closely, and this is where everyone should be looking most closely."

Concerning the materials used in production, John Davies' story of the disparate batches of modules – one operating normally, one riddled with issues – delivered to the same site by the same manufacturer provides an anecdotal example. He says that the issue of varying batch quality suggests "it's a bill of materials (BOM) issue, they're getting their cells or wafers from different sources". Due diligence needs to be done to investigate the BOM and the plants where the components for a module are being produced, Davies says.

"Unknown, unverified, untested"

This brings us to the second of the factors that might influence an oncoming quality dip: supply chains. The largest manufacturers have grown massively and at an incredible pace in the last few years, which can strain their supply chains. Kedir says: "We've had issues with large, Tier-1 manufacturers who switch some of their primary components to unknown, unverified, untested suppliers in China and ship them to the US. And sometimes it's happened without the knowledge of a lot of the people within the company."

He continues, saying that RETC has encountered frequent issues in the field

Technically speaking

When it comes to module technology, the CEA told *PV Tech Power* that it did not have sufficient data for anything other than passivated emitter/rear contact (PERC) modules to draw any technological conclusions. This will presumably change in the coming year or two as n-type modules – particularly TOPCon – come to replace PERC as the market-leading tech.

Kedir says that, from the years of data collected by RETC, he believes that the industry has improved testing, assessing and stabilising technologies before they release them to the market.

For example: "PERC technologies, at the very beginning, were susceptible to light and elevated temperature induced degradation (LeTID), which was solved very quickly and the industry was able to react in a way that was pretty amazing."

He continues, saying that TOPCon is experiencing some issues with UVID but that the technology is too new to have revealed all of the potential snags it might hold. "Stupid failures", as he calls them, are rare and the shortfalls from a technological standpoint tend to be found in places that the manufacturer couldn't have planned for.

Bifacial modules, for example, introduced far more frequent instances of hail damage because their glass is generally thinner than in modules with a single glass face and a backsheet. The introduction of double glass, however, allowed far less moisture to penetrate into the cell.

In recent years, Kedir says that RETC has found issues due to the size of modules – much bigger panels with thinner glass to reduce weight, which has produced "a lot of mechanical integrity issues…the glass breakage is a pretty big issue that we see in lab testing and field forensics".

"Certain things are getting better, while other things are getting worse", he says.

John Davies of 2DegreesKelvin notes an increase in issues during the transition to n-type technology: "What I would say is that since we've gone to n-type, the volume of affected cells has gone up."

Davies' observation relates to speculation from *PV Tech* head of research, Finlay Colville: "Until recently, at least the wafer type was largely a constant. But now the industry is going through a rapid change from p-type to n-type cell types and while there is an argument that n-type substrates should make better quality modules, everything still has to be understood and checked."

The industry has improved testing prior to product release, says RETC's Cherif Kedir

that have transpired due to supply chain swaps. "Sometimes the manufacturers came clean and told us and the developer and we conducted testing", though he says that in some cases this testing resulted in 100% failure rates for materials, even after multiple rounds of testing.

Upstream supply chain issues do reverberate down to asset owners 'on the ground'. According to Julian Elsworth, portfolio director at UK-based solar asset owner Foresight Group, the company is increasingly looking to source its modules from a "whitelist" of manufacturers in response to both concerns from financiers over forced labour in the solar supply chain and the lessons learned over the last ten years about module quality.

Having entered the solar industry a decade ago, he says the company has learned to prioritise the ability to test throughout the supply chain where possible: "You can send technical advisors to factories, so at that stage of the process you can check that everything's being done correctly." He says that if a manufacturer claims not to accommodate a certain testing method, asset owners now have more ability to buy from someone who does. In such cases, "they're probably hiding something", Elsworth says.

This applies to traceability in terms of quality assurance, but also to the issue of forced labour traceability that has a bearing on manufacturers' supplies. As the PV industry is forced to scrutinise the provenance of its supply more closely, due to government, investor and consumer pressures, more uncertainty emerges. The reality of the situation – that close to half of the polysilicon produced in China comes from Xinjiang, and over 80% of the world's polysilicon comes from China – could exacerbate the sort of supplier shifts that Kedir mentions, which have already caused quality issues.

Elsworth says: "We need to also look from that ESG angle; a lot of our bigger investors are starting to ask us about that problem, so we need to address that."

New players, new problems?

Turning west, everyone reading about solar PV in the US is aware of the Inflation Reduction Act (IRA), introduced by the Democrat government in 2022 with over US$360 billion in tax credits for renewable energy deployment and manufacturing. At the same time, the US market has been plagued with supply issues off the back of the twin-pronged attack of the Uyghur Forced Labor Prevention Act (UFLPA) and antidumping/countervailing duty (ad/cvd) tariffs.

In the face of supply issues, the emergent module manufacturers that have set up in the US in the wake of the IRA may have to scout around for suppliers to meet their demands – possibly resulting in the same "unknown, unverified, untested" producers Kedir mentions (though not in China, obviously).

He says that this will "hopefully" not become an issue for the big companies setting up in the US, like Canadian Solar, Jinko Solar, Qcells et al., particularly if the IRA is able to deliver on its full potential. However, newer and smaller entrants into the solar market may have to overcome quality issues that can sometimes be unavoidable.

"I really hate the statement that startups and small companies cut corners," Kedir says, "but it's the reality. They don't necessarily cut corners because they want to, but because they have to."

"If you are Jinko or JA and you have the purchasing power to go to the best backsheet or glass manufacturers and you say, 'I want to buy 20GW or 50GW', they're going to mobilise their entire manufacturing and they're going to give you the best price possible."

Smaller companies don't have that purchasing power. "I've seen manufacturers be completely cut off from their supply chain," Kedir continues. "Cell suppliers, backsheet suppliers…just did not have the capacity to deal with someone who was buying 50MW or 100MW, and they ended up having to source alternative materials. Again, not because they wanted to, but because they absolutely had to."

Diversified solar supplies are a good thing when it comes to energy security, national economic growth and a fair marketplace. Governments and trade bodies in the US, Europe and India are all trying to stimulate domestic PV manufacturing capacity to insulate their economies from China's dominance of the PV supply chain, and new companies can offer alternative outlooks, stimulate change and drive new technologies.

However, the solar module production process consists of a well-oiled set of production lines, and George Touloupas of the CEA says that this takes time to perfect: "Our experience from performing quality assurance and production oversight over many GWs of projects has repeatedly shown that new factories take months to ramp up and iron out quality issues, and new manufacturers take even longer to improve."

This sentiment is echoed by Niclas Weimar of Sinovoltaics: "Specifically in the US, the mushrooming of new factories across the country will bring a tremendous number of new opportunities, but at the same time there will also be quality challenges."

In January 2024, Sinovoltaics announced plans to enter the US market in direct response to growing US capacity, the increased number of producers and the dramatic drop in prices for Asian-made modules.

"From our decade-long experience with PV module manufacturing in Asia, I expect newly set up factories to face their fair share of initial quality and related procedural issues," Weimar says. "Be it with the setup of robust quality management procedures specific to PV module manufacturing, the calibration of manufacturing and measurement equipment, the quality challenges of product design and certification, the creation and constant updating of quality standards or the establishment of proper quality control procedures. Add to this the current shortage of PV-skilled labour in the market."

It's unclear what the next year will hold for solar manufacturing, and what market forces may mean for the panels themselves coming off production lines. But the seeds for a looming quality problem may well have already been sown.

The combination of falling prices, shifting supply chains and a wider pool of new manufacturers, coinciding with ever-greater demand and deployments for solar PV in a widening marketplace, seems like a recipe for uncertainty in the industry. Most pertinent for any observers will be the way that downward price pressures impact the big-name manufacturers.

Kedir offers some cautious optimism: "I hope that maybe some manufacturers are going to be responsible enough to slow down their manufacturing, maybe shut down a few lines so that the industry adjusts.

"But humans are a funny bunch. What may end up happening is some manufacturers are going to say, 'I have deep pockets, I'm going to see this through and drive everybody else out of business'."

The truth is that "the risk is there", he says. "We're here to keep the industry honest." ■

Turn to p.20 for PI Berlin's overview of module quality trends over the last ten years

New technologies, new issues

PV module quality | As PV module technology has evolved, so too have the quality challenges associated with the new technologies that have appeared, matured and been superseded. Fei Lu and Stephen Xuereb of PI Berlin draw on over a decade of experience with an overview of the present trends in module quality assurance and likely future challenges as technology continues to change

Within the last decade, PV module technology has changed and developed drastically. After years of similar-sized 60- or 72 poly-crystalline AL-BSF p-type cell modules, there has been a dramatic shift in size and cell technologies. While quality has continued to improve, the fast-paced changes have introduced new issues (and some old ones from the past) that the industry is currently addressing. PV module manufacturing has experienced a remarkable expansion over the last decade, increasing tenfold globally to meet the increasing demand for renewable energy. According to International Energy Agency (IEA) forecasts, this trend is set to continue at an elevated pace, with investments in the pipeline set to increase global solar module manufacturing capacity from 640GW in 2022 to over 1,200GW in the medium term. This growth has led to new module manufacturers and their sub-suppliers in the supply chain, including new factories being set up rapidly across Asia.

PI Berlin has been in a unique position during the past ten years monitoring the effects of this rapid growth in terms of product quality. Independent quality assurance of manufacturing processes and materials is crucial to assure the reliability and long-term performance of PV modules. The experience and knowledge presented in this article will share insights and trends in quality that PI Berlin has observed through factory-based quality assurance on over 100GW of PV modules and the quality of over 15GW of global PV systems. The quality data below will show the defect trends and reflect technology and product innovations within the industry.

The importance of quality

The PV industry has faced several major challenges in the past few years including:

- Changes related to new materials, such as new solar cell structure (n-type solar cells), new encapsulant materials (Polyolefin, and PEP which is a mixture of polyolefin and ethylene-vinyl acetate);
- Changes related to manufacturing processes for new technologies such as tunnel oxide passivated (TopCON) and heterojunction (HJT);
- Lack of long-term durability results for new technologies like TOPcon and HJT;
- Lack of physical understanding of failure mechanisms that occur with new solar cell structures;
- The adoption of bifacial glass-glass modules instead of monofacial glass/backsheet;
- The introduction of ultra-large modules based on super-sized silicon wafers, which has proliferated in number and size of module types in the market and triggered new rounds of quality testing and changes in system integration;
- Supply chain disruptions due to the COVID-pandemic and geo-political 19 conflicts resulting in more suppliers and factories to meet demand;
- Requirements for higher standards of environmental and social governance, including greater transparency in the silicon supply chain.

Supply chain disruptions in the industry have increased buyer and investor concerns, not only for quality, but also for completing projects on time. Significant project delays have been observed due to COVID-19 restrictions, increasing shipping costs, shortage of shipping capacity, new import rules, government tariff-circumvention investigations or supply chain traceability requirements.

Apart from delays, these disruptions have resulted in direct challenges to module quality coming from unexpected or last-minute switches in manufacturers, factory locations, module types or bills of materials. Manufacturers have also increasingly had the upper hand in supply negotiations which inevitably means that some quality requirements, demanded by the buyer, may have to be sacrificed to secure supply.

It is crucial to pay close attention to quality to ensure the longevity and reliability of a PV project. Completing PV projects using alternate bills of materials or working with unfamiliar suppliers heightens the concerns of buyers and investors who have specific quality expectations and want to protect their assets.


Credit: PI Berlin

PV modules undergo a pre-shipment inspection. Quality trends have evolved in step with emerging module technologies

Trends in PV module quality

Looking back at Al-BSF and PERC

Al-BSF and PERC solar cells and modules have dominated the market for 20 years, with their own set of module quality issues. The most common of these are:

- Backsheet degradation
- Potential-induced degradation (PID)
- Light- and elevated temperature-induced degradation (LeTID)
- Junction box failure

Backsheet degradation: Backsheet degradation in field-exposed PV modules has been observed and reported for several years [1] and is the major issue affecting the safety and performance of older PV plants with backsheet modules. It is generally acknowledged that a degradation mechanism initiated by front-side UV radiation or along the cell connectors indicates the appearance of thermo-mechanical stresses [2]. Chalking and cracks are the most prominent degradation features that can lead to reduced electrical insulation properties and consequently increased electrical hazards.

This safety issue, also potentially leading to mechanically catastrophic damage, was primarily caused by poor-quality polymers that were used during a specific period in the early 2010s.

Potential-induced degradation: PID has a variety of root causes for the different types of solar cell technologies. PID-shunting is the most common type of PID in conventional p-type AL-BSF and PERC PV modules. Extensive studies have shown that sodium ions (Na+) under the negatively biased conditions from the glass drift through the SiNx AR coating towards the interface between the Si and the AR coating, and can penetrate into crystal defects crossing the n+-p junction. This results in significant shunting of the cells and degrades their efficiency and module power output [3]. PV plants with high levels of PID in their modules led to catastrophic drops in energy production and revenue, leading to the eventual replacement of large quantities of modules.

Light- and elevated temperature-induced degradation (LeTID): Light-induced degradation (LID) is a common phenomenon that leads to efficiency degradation of crystalline silicon solar cells. The degradation rate of LID is relatively fast and can lead to saturation within a few days. The mechanism of LeTID in crystalline silicon has also been intensively studied. Current research shows that the cause of LeTID may be related to hydrogen or other impurities, such as metals contained in crystalline silicon solar cells, but the specific cause of LeTID has not been determined. During heat treatment, hydrogen trapped in the dielectric layer is released, which can passivate most of the defects and improve the efficiency of the solar cells. However, recent studies have shown that hydrogen-related association and dissociation processes may affect LeTID [4]. While the degradation due to LeTID can be reversible, the impact on energy production before detection and correction can be significant for PV plants.

Junction box failure: Junction box reliability is one of the most crucial issues for PV modules during verification testing and operation in the field. Not only does it have a high failure ratio among various faults, but it usually accompanies severe safety and warranty problems during the PV system lifetime. Burnt bypass diodes have been reported as the top failure of the module in the laboratory and field. The breakdown point at the PN junction chip is commonly considered the root cause for this failure, which results in energy over-stress and consequently evolves into a burnt junction box. Besides this root cause, improper cable welding and wiring demonstrates that it induces arcing initiated by a strong electric field (bigger than the breakdown electric field for molecules) with small gap distances between the cable and the metal contact.

In order to mitigate these risks, PI Berlin recommends laboratory testing as part of the qualification process to evaluate the reliability of PV modules quality issues related to backsheets PID, and LeTID. Based on these results, uniquely tested bills of materials (BOM) should be agreed upon during the procurement phase and verified using material compliance checks during production supervision.

Current trends

Over the past ten years, PI Berlin has independently assessed the quality of more than 100GW of modules from over 100 PV manufacturers, gaining valuable insights into manufacturing and product quality trends within the PV industry.

A remarkable fluctuation of annual defect rates has been observed in Figure 1 from 2016 to 2022. The PV module industry maintained a lower defect rate (0.65%) in 2016 due to the maturity of Al-BSF polycrystalline silicon solar cell module. Monocrystalline PERC silicon solar cell modules and new technical innovations in materials, processes and equipment, such as glass-glass modules and bifacial modules resulted in an increase in quality issues and PV module defects. As monocrystalline PERC solar cell modules matured, defect rates decreased, until a rapid shift in larger wafer and multi-busbar technology generated increased module defect occurrences in 2020.

Typically, module manufacturing has several processes that introduce risk to module quality. By analysing the source of defects shown in Figure 2, rework/lay-up/cell soldering/EL imaging/framing are identified as top-five defect sources. Together they contribute to >65% of total defects in the module production line. Rework and lay-up replaced cell soldering as the most common major contributor during the past two years. This trend proves that glass-glass and larger module formats increased the impact on module production lines and were the cause of many of the quality defects. As multi-busbar soldering technology becomes more mature and stable, cell soldering will likely no longer be the top module quality issue.

New challenges observed

As PI Berlin looks to the future of module technology and manufacturing, there is real value in understanding historical trends and being able to apply that knowledge in assessing and predicting upcoming patterns. Being able to access and observe changes in production and technological innovations gives us an insider's perspective on potential upcoming trends. By combining that with our expertise in how trends take shape, we are better prepared to evaluate and forecast changes in module performance. Here are some of the main issues we see coming in the near future:

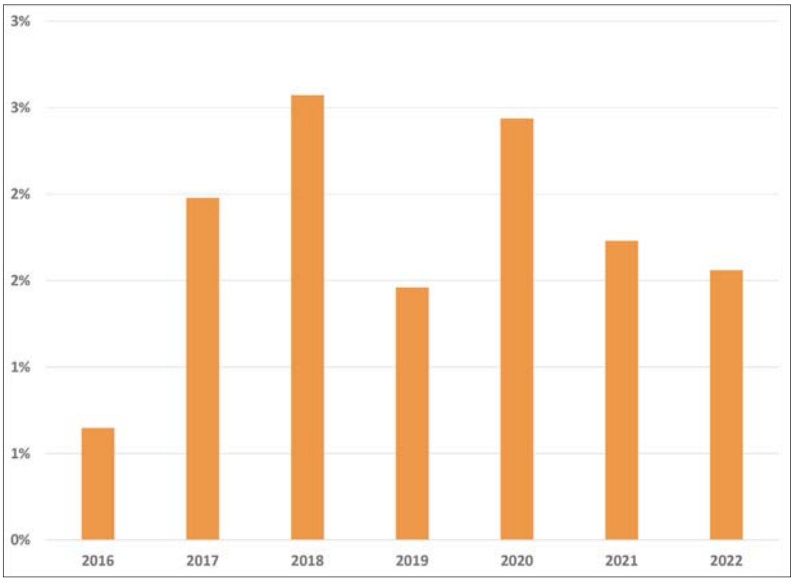


Figure 1. Annual aggregate defect rates in newly built PV modules

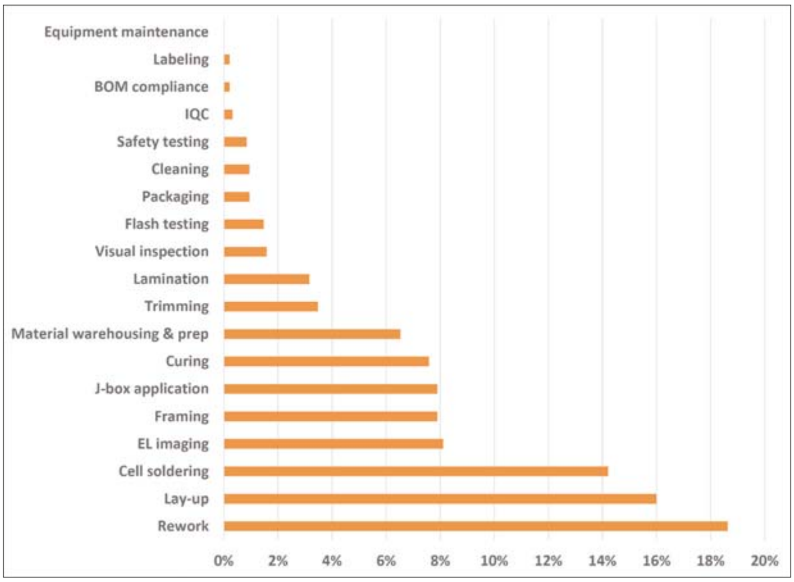


Figure 2. Statistics of PV module defects. Source based on PI Belin database (2022)

- Rapid technology change without long-term reliability test results;
- New soldering technologies such as conductive glue, low-temperature soldering and zero busbar overturn the requirement of soldering;
- Extreme cost reduction of raw materials, such as thinner glass, thinner encapsulant materials, copper plating for metallisation, silver-coated copper pastes etc.;
- Extreme high throughput of production causes a narrow process window;
- Thinner but larger wafers require longer and more complicated process steps;
- Personnel are inexperienced with process and quality controls due to the aggressive capacity expansion of manufacturers.

Challenges and potential risks occurring during this transition may not be caught by manufacturers' quality management systems. Hiring a third-party quality assurance firm is necessary to maintain the production of a quality product.

Glass in focus

In 2023, around 40% of the modules manufactured were glass-glass modules, and it is expected that this will further increase to 70% over the next few years, according to the ITPV Roadmap Report 2023. The shift towards glass-glass modules was intended to bring many advantages, including humidity resistance, bifaciality and reliability. The reliability aspect was expected due to the rigidness of the glass on both sides, rather than the more sensitive polymer backsheet. Backsheets experienced various levels of degradation over the years depending on the materials used and the local environmental conditions. Unfortunately, due to many factors that will be addressed below, glass breakage on site after installation has become a significant issue in the industry that must be addressed. PI Berlin has been involved in a number of PV plants over the last two years investigating the root cause of these failures. The failure rate in these PV plants was between 1 and 10%, and the 10% was found in a 150MW plant. The importance of focusing on the glass as part of the independent quality assurance process has become more critical.

The first factor affecting the reliability of glass-glass modules is module design, in particular the size of the modules themselves. PI Berlin's primary experience with glass-glass modules in the past was with thin-film modules. Compared to those modules, the current modules on the market are up to four times larger, and on average modules have doubled in size in the past ten years. The introduction of half-cut cells and the butterfly architecture requires three holes in the rear glass for the junction boxes. In addition, glass thickness has been reduced, as well as the frames, while also shortening the mounting rail or clamp position. All these design factors result in a less rigid module, which is becoming a critical load-bearing part of the mounting structure.

The second critical factor is the glass design and quality. Glass/backsheet modules used 3.2mm fully tempered glass, which has high flexural strength and a larger range of temperature change resistance. The glass-glass modules currently on the market use 2mm (or even thinner) heat-strengthened glass, which has almost 50% lower bending strength and temperature resistance. Due to the increased demand in glass and stresses on their supply, the industry sometimes uses non-solar glass for the rearside and also more suppliers are required who may not have the same level of quality as more experienced suppliers.

As part of the investigations into glass breakage, a third factor arose which is the gap in the testing and certification of glass for modules. As glass in the past was not considered a reliability issue in previous module designs, little attention was paid to the specification and test requirements of the glass itself. Since there are no PV-specific glass test standards, questions have come up over whether the safety factors and minimum test loads applied for the mechanical load test of modules are sufficient. In addition, with the variety of mounting structure designs and tracker systems used in combination with the local loading characteristics, the single module testing method is insufficient to represent actual operational conditions.

Finally, several other factors have been identified during PI Berlin's investigations that have resulted in glass breakage. Other module defects, such as hotspots caused by shunting, poor soldering or cell breakage, have led to glass breakage due to the extreme localised temperatures. Improper installation due to wrongly applied torque values has caused cracks in the glass originating from the clamps. Extreme weather conditions have also been the cause in some cases, such as excessive hail events and heavy snow conditions. With the increasing volatility and intensity of weather events due to climate change, it is expected that the resiliency of the modules under such harsh conditions will become more of an issue.

With hundreds of gigawatts of glass-glass modules already in operation and terawatts to be installed in the coming years, our industry will have to pay much more attention to the glass component of modules during quality assurance. Starting at the pre-qualification level in the procurement process, module manufacturers need to provide more information about the glass being used and the testing they have undergone to meet the local conditions of the PV plant. The industry must develop and adopt testing standards and certification specific to glass applications for solar. Module testing has to continue to develop beyond the current standards to ensure they are relevant for the current size and design of glass-glass modules.

Finally, the quality control conducted by manufacturers and the quality assurance provided by third parties needs to be expanded to focus more on the incoming glass inspection and controlling of edge treatment and hole drilling during production. Only with strong cooperation between module manufacturers, glass suppliers, testing laboratories and R&D institutes will the solar industry be able to ensure the reliability of glass-glass modules in the coming decades.

Silicon supply chain requirements

The role of quality assurance has continued to develop not only at a purely technical level but also to include topics related to sustainability and environmental, social and governance (ESG). Investors and purchasers of solar PV equipment want to ensure that the products they source and the suppliers comply with stringent ESG policies. Legislation in the US and EU regarding due diligence and supply chain traceability has put additional pressure on the industry. In particular, the sourcing and refinement of polysilicon in PV modules have come under international scrutiny based on suspicions of forced labour being used.

To address these concerns, buyers are increasingly seeking independent verification of the origin and production of materials used in the modules and their assembly. Quality assurance providers like PI Berlin have been asked to conduct supply traceability and ESG audits to assess the risks that the modules involve a supply chain that is not consistent with their company's ESG policies or legislation, and may potentially be seized or blocked on import from overseas.

Over the last two years, PI Berlin has conducted over 30 such traceability audits in module manufacturing facilities in China and across Southeast Asia. Initially, the manufacturers were not well prepared to cooperate in such audits, as they had no dedicated teams or training regarding this topic, there were concerns around confidentiality and their traceability systems were inadequate to track the chain of custody of the polysilicon. In the last year or so, the larger manufacturers, in particular those with a high level of vertical integration, have drastically improved their traceability systems and have established internal teams who are well versed in the ESG requirements of investors. These manufacturers are now taking proactive steps by contracting independent ESG and traceability audits for their module factories. They have also managed to shift their silicon supply chain completely from the regions of most concern for potential forced labour cases.

As a result, the focus of the quality assurance provider has shifted to integrating the supply chain traceability assessment into the inspections taking place during module production for specific projects. Here, the role of the inspector is to verify that the bill of materials for the main components in the buyer's module supply agreement is not only certified but also that the origin of the silicon-related components (i.e. cell, wafer, ingot, polysilicon and MGS) can be confirmed. While some manufacturers are able to provide clear evidence down to the polysilicon supplier through their procurement systems and documentation, others rely on making self-declarations while they continue to improve their traceability capabilities.

Continued progress in the area of ESG and traceability is expected to be made through the Solar Stewardship Initiative (SSI) which was founded by SolarPower Europe and Solar Energy UK in 2021. The SSI is a multi-stakeholder initiative that includes investors, manufacturers, NGOs and other critical stakeholders in the industry, to foster responsible production, sourcing and stewardship of materials in the global solar value chain. An ESG Standard has already been established in 2023 and a Traceability Standard will be developed in 2024. These standards will give both buyers and manufacturers clarity on the requirements for the industry and comfort that the products used in PV projects meet these requirements.

Conclusion

Undeniably, new technologies and new materials have an immense impact on every facet of solar PV modules. The continuous increases in conversion efficiency and further cost reduction serve as a catalyst for innovation and improvement. On the other hand, these rapid changes over the last few years present also challenges in terms of the manufacturing quality of modules. Past experience has shown how the industry has paid a high price for premature degradation defects affecting their investments, such as PID and backsheet cracking. The latest technologies are bringing their own new challenges such as insufficient soldering strengths and glass breakage. Independent quality assurance plays a crucial role in managing these risks from the product qualification process to the manufacturing in the factory and until the modules meet the delivery site.

Furthermore, buyers and manufacturers have new requirements with respect to ESG and supply chain traceability that introduce new challenges in terms of sourcing materials, adapting procurement systems and increasing transparency. The solar industry is known for its incredible ability to change and improve at an astonishing pace, and quality assurance will continue to accompany this growth to protect the expected growth in the future. ■

On p.24, TÜV Rheinland offers further insight into the evolution of module testing

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Under the microscope

Testing | Inspection companies are key in enforcing and setting the quality standards underpinning module performance. TÜV Rheinland's solar segment manager, Lukas Jakisch, tells Will Norman how they are keeping abreast of the rapid pace of technological change

Between 2012 and 2022 the world's total installed solar PV capacity increased more than tenfold, from 100GW to 1,185GW. There is now more solar PV on the ground than the entire installed electricity generation capacity of the EU in 2022. In short, the PV market is booming.

Simultaneously, the number of modules and technologies available on the market has grown and shifted and module prices have gone through the floor. By some estimates, annual production capacity in China is currently three times global demand, and 2023 has seen all the big players expand their capacities tremendously. This has led to concerns that manufacturers may resort to cost-cutting measures that could compromise module quality.

PV Tech Power spoke with Lukas Jakisch, solar segment manager at PV testing and certification company TÜV Rheinland, about the developments and challenges facing the sector.

PV Tech Power: To what extent are standards being monitored and updated to ensure they remain in step with the pace of technological change in the industry?

Lukas Jakisch: The answer is surprisingly simple: the legislator sets the rules and regularly publishes new or revised norms and standards through the relevant authorities or committees such as the IEC [International Electrotechnical Commission]. This is where industry experts such as testing companies, research institutes and manufacturers can contribute their experience from laboratory and field tests. We also use our findings to help make standards, and ultimately products, better and safer. The final decision on changes to standards and their content is made by the government authority or the relevant committee or body to which TÜV Rheinland, as a member, proposes appropriate adjustments and improvements.

How have testing houses kept up with the rapid development of PV technology in recent years? Can you give some examples of how you've had to modify your testing processes in step with the introduction of a new technology?

I can give you a couple of examples. First, let's look at the dimensions and power of PV modules and their cell sizes. All three have continuously changed or increased in size in recent years and exceeded the capacity of current test equipment. One way to overcome this challenge is to work with so-called representative samples (e.g. for very large façade modules). In this case, smaller samples are tested. The results can also be scaled up to larger samples for a selection of tests. Another obvious consequence is that test centres such as TÜV Rheinland will have to adapt or expand their facilities accordingly. This is particularly true of climate chambers and solar simulators. For example, we have recently invested several million euros in new facilities at our company, which also take into account a further increase in system dimensions in the future.

Another example is new (cell) technologies. The Polish PV start-up Saule recently launched a PV module with a new cell technology, so-called perovskite cells, which we have tested and certified according to the IEC TS 63163 standard. The challenge: new cell technologies require new stabilisation processes and new methods for measuring performance. In this context, test centres such as TÜV Rheinland often develop their own test procedures, known as 2PfGs. These take into account both the currently applicable standards and the challenges of a new cell technology arising from the specific case in question. These standards can be adapted to the respective market situation much more quickly than international standards, which involve many different market players. Often enough, these standards, in turn, serve as a model for IECs. For example, when bifacial cells came onto the market, TÜV Rheinland was the first testing organisation in the world to respond to this technological innovation with a corresponding 2PfG standard. This standard was and still is the model for today's IEC standard 61215:2021. The "Sharp Edge Test" requirement in IEC 61730:2023 (the current safety standard for PV modules) is also due to measurement experience and preliminary work by in-house solar experts, who thus developed a template for a new IEC standard.

What can ensure that current testing standards and guidelines are up-to-date and sufficiently comprehensive?

The interplay between technological change and the evolution of the regulatory

Credit: TÜV Rheinland

Test centres such as TÜV Rheinland have to continuously adapt test facilities in step with changing PV technologies

framework to ensure that innovations can be used safely is a matter of course – whether in the energy sector, mobility, or digitalisation. In this respect, the process of adapting to technological change is part of the day-to-day business of testing organisations such as TÜV Rheinland. However, it is important that new findings are regularly and promptly incorporated into new or revised standards. This is where the relevant authorities are called upon to catch up with the regulations. But testing companies are also actively involved in further development. For example, by offering audits that go well beyond existing legal requirements, TÜV Rheinland can identify anomalies that would not have been noticed in "standard" audits. In turn, we share these findings with the regulatory authorities and incorporate them into standards and norms.

What are the most common defects you encounter when dealing with new technologies?

In general, the durability, performance, and range of applications of PV systems have improved over the past decade. This has been helped by the fact that experience gained in the laboratory and in the field has been fed back into current standards, and quality assurance processes have thus been continuously improved. At the same time, however, we have seen that there is always a lack of basic knowledge about new technologies. This is partly due to the constant changes and partly to financially motivated savings potential in materials and components, some of which are not sufficiently qualified. In addition to quality problems, this also leads to failures in the field due to both light-induced and potential-induced degradation. The latter can often be countered with simple measures, provided the problem has been identified by the manufacturer. Other degradation phenomena include: LeTID, UVID, chalking, browning and cell microcracking. Static factors also play a role. Plants are getting bigger and heavier. In open-air systems in Spain, we have investigated glass-glass modules that bend. Their own weight was too much for the support structures that had been installed. In the field inspections we have carried out, installation errors are one of the most common defects and causes of failures. For example, combinations of connectors from different manufacturers are used (cross-installation), or connectors are left open for long periods of time, exposing them to the elements, dirt, and corrosion. For several years, TÜV Rheinland has offered to qualify and certify installation companies. All processes, staff qualifications and materials used in the company are assessed and installations are randomly tested on site. The audit is repeated every year.

There are concerns that the combination of falling module prices, oversupply and increasing global production capacity will impact on PV module manufacturing, particularly as companies look to cut production costs – can you address this?

Well, we don't have a crystal ball. But we do have the ability to counteract this very risk by offering testing services. For example, we often see safety-related quality defects in cable and insulation material. One possible reason is that if extruders run too fast, the extruded insulation sheath can show irregularities. In special ovens, we test photovoltaic components for their long-term thermal behaviour between minus 40 and plus 125 degrees Celsius. The target for conductor material, for example, is 125 degrees Celsius for 5,000 hours. Our services, therefore, also include component testing that takes into account typical manufacturing defects that can occur in times of high price pressure and production cost reductions.

Another example is solar glass: to reduce cost and weight, solar glass is becoming thinner and thinner and may not be able to withstand the stress. The thickness is now down to 1.6mm – five years ago it was 3 to 4mm. We can simulate the required and real stresses on solar glass in our laboratories and materials that are not suitable for the application would stand out.

However, I would like to point out one thing in this context. In the EU and the UK, there is no requirement for manufacturers to have equipment tested by independent testers such as TÜV Rheinland. The legislation only requires imported products to be CE-compliant. It is up to the manufacturer to decide how to

Credit: TÜV Rheinland

A strict definition of quality requirements when purchasing PV modules and components would help further minimise investment risks

meet this requirement. In light of the current public debate, we urge manufacturers to rely on independent testing expertise such as that provided by TÜV Rheinland. Investing in quality assurance reduces the likelihood of serial defects and thus the risk for investors, and ultimately benefits the entire industry.

What are the main challenges facing PV module quality control today and how do you anticipate having to adapt to ensure your testing services remain attuned to the demands of a fast-changing industry?

The fact that technological change brings both technical progress and new technical challenges is nothing new. Particularly in the case of more recent innovations, certain new features sometimes only become apparent under real external conditions, because the corresponding problems only occur in certain – previously unknown – constellations. Of course, it is important that new, reliable findings are quickly incorporated into the applicable standards and norms. In this respect, the further development of existing technology and standards is an ongoing process. At the same time, it can also be said that it is precisely because of these interactions that numerous standards have been further developed or newly created in recent years, leading to an improvement in quality assurance in the PV module sector.

What lessons have been learned from the solar boom that could inform manufacturers or testing houses in the face of a coming downturn?

From the point of view of a testing company, the following conclusions can be drawn from the laboratory and field tests carried out in recent years. For existing systems, early and regular inspections would help to counteract degradation such as PID, thus meeting quality requirements and reducing additional costs for repairs and maintenance.

For new systems, a strict definition of quality requirements when purchasing PV modules and components would go a long way towards further minimising investment risks. This includes tests such as performance measurement, mechanical tests (mechanical stress such as snow and wind loads, environmental simulation in climatic chambers with humidity, high and low temperatures, mechanical stress due to temperature changes), electrical safety, simulation of electrical faults (e.g. PID, LeTiD, UViD).

The application of minimum standards according to IEC norms, combined with extended stress tests and characterisation, enables consistent qualification of the bill of materials (BOM), accompanying production inspections to check the BOM and production quality. In addition, the demand for safety, durability and cost-effectiveness of PV products requires the professional and quality-assured use of laboratory services, high-quality products, professional installation, and regular maintenance. What is needed are system investors who do not invest from the outset based on calculated maximum returns with considerable risk, but instead give quality and quality assurance financial leeway, practise risk management and thus ultimately lead the entire project to economic success. ■

Is Japan’s solar 2030 PV target feasible?

Market update | Solar and storage are playing a central role in Japan’s goal of enhancing energy security. Uranulzii Batbayer and Aniket Autade of Rystad Energy look at recent developments in the market to assess Japan’s progress in reaching its 2030 targets

Sonnedix is one of the leading developers in Japan, where new PV installations reached 1.1GW in 2023

Credit: Sonnedix Japan

As a leading economic power in Asia, Japan has emerged as a global frontrunner in the transition to carbon neutrality. Despite facing a significant decrease in energy self-sufficiency, dropping from 20% to 11.3% after the 2011 Fukushima nuclear accident, Japan remains determined to enhance its energy independence. The country is targeting a 36-38% share of renewable energy in its power mix by 2030, with a primary focus on increasing self-produced renewables such as solar and wind.

Solar energy, in particular, has played a pivotal role in Japan’s renewable landscape, with a targeted 14-16% share of solar PV by 2030. In pursuit of this goal, Japan has undergone substantial solar PV development since 2012, offering a feed-in-tariff (FiT) subsidy system that provides a fixed payment for each kilowatt-hour produced over periods of up to 20 years for approved renewable generators. However, the FiT system imposed a growing burden on end-users, and generators became detached from electricity demand.

From 2022 onwards, Japan introduced a feed-in-premium (FiP) subsidy system, designed to incentivise companies to generate more power during peak hours and less during off-peak periods. Presently, both FiT and FiP systems are being offered, but there is a gradual shift towards adopting FiP exclusively. The FIP system ties generators to market prices and this approach provides greater incentives for increased supply during peak demand hours, potentially facilitated through the use of battery storage.

However, the transition from FiT to FiP introduces elements of competition and instability due to price volatility and imbalance risks. The shift may make the subsidy system less attractive for certain businesses. Additionally, challenges related to land scarcity for solar PV installations contribute to more subdued growth in new solar installations.

Japan solar PV market in 2023

With 1.1GW of new solar PV installations in 2023, the total installed amount of solar PV reached 122GW, constituting 12% of Japan’s overall power mix. While 2024 is anticipated to witness a slight uptick in installations, the trend leans towards smaller projects below 50MW in scale.

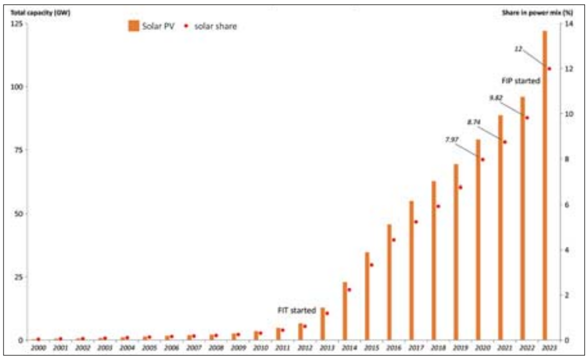

Figure 1. Cumulative solar PV installations in Japan over the years

Source: Rystad Energy PowerCube

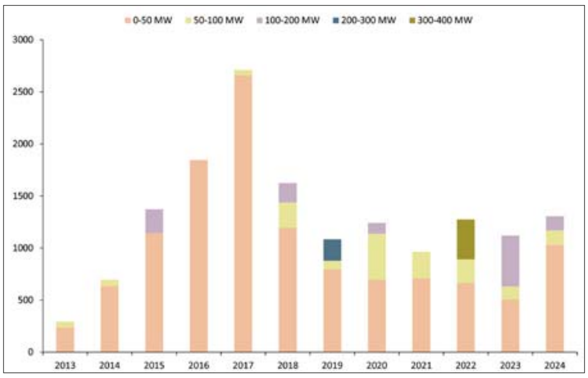

Figure 2. Installed capacity size of solar projects, MWac

Source: Rystad Energy PowerCube

In 2023, the installed capacity of solar PV remained under 200MW, with 45% of projects falling below the 50MW threshold. Notably, installations were predominantly concentrated in Hyogo, Miyagi, and Mie prefectures. In the last year, foreign companies, including Vena Energy from Singapore and Sonnedix from Spain, accounted for 47% of the developers and secured positions in the top five solar PV developers in Japan.

When conducting an economic analysis (with a discount rate of 5%) of solar PV projects implemented in 2023, categorised by project size (under 50MW, between 50 to 100MW, and over 100 but less than 200MW), the net present value (NPV), which signifies the project's profitability, was notably highest for Pacifico Energy's 120MW Sanda Mega Solar project, in Hyogo Prefecture, and lowest for the 34MW Samegawa Aosono Megasolar project, in Fukushima Prefecture. The levelised cost of electricity (LCOE), representing the lifetime cost of electricity generation, was highest for projects under 50MW. Interestingly, unlike NPV or LCOE, payback year did not exhibit a direct correlation with project capacity but ranged from eight to 11 years.

In general, larger capacity projects, with a higher NPV and lower LCOE, appear to yield higher profits. However, it is acknowledged that such projects may require more extensive land and entail higher initial costs, likely contributing to the observed trend of limited installations of larger capacity projects.

Despite these developments, achieving the ambitious target of generating 36-38% of electricity from renewable sources by 2030, especially concerning the solar PV sector, appears challenging at the current decelerating rate of installation. Exploring alternative avenues for accelerating solar PV deployment becomes imperative to bridge the gap and meet the set targets.

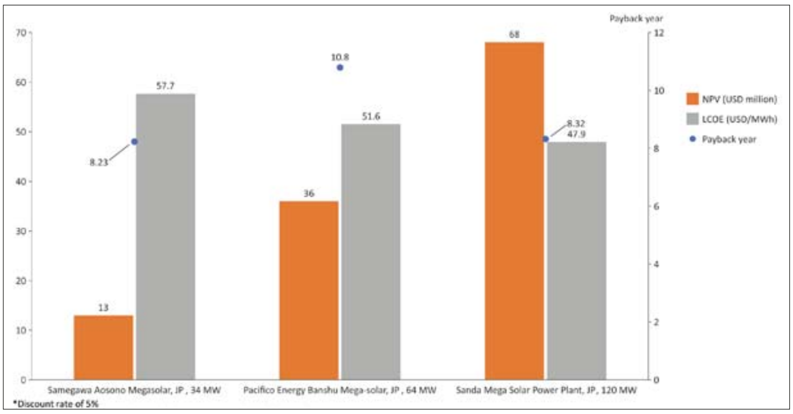

Figure 3. Economic analysis of different sizes of solar PV projects installed in Japan in 2023*

Source: from Rystad Energy Renewables economic analysis dashboard

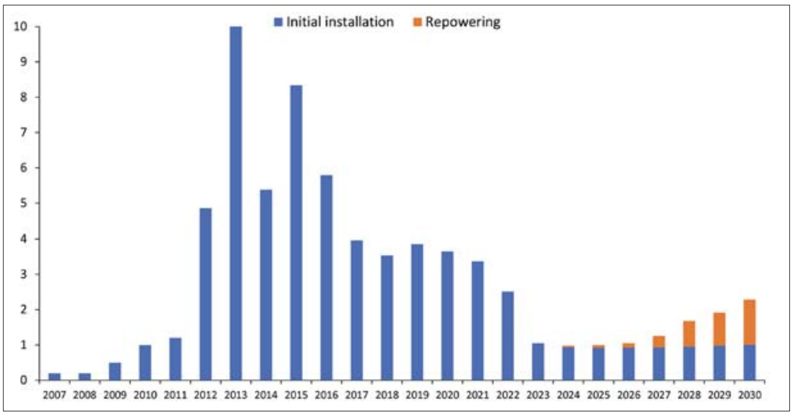

Figure 4. Yearly Installed capacity size of rooftop solar projects in Japan, GWac

Source: Rystad Energy Rooftop PV Analysis dashboard

Rooftop solar in Japan

In recent years, Japan has witnessed a surge in rooftop solar installations, with 1GW of rooftop solar capacity added in 2023, taking the total installed capacity to 59.6 GW. This positive trend is expected to continue in the coming years, driven by both the repowering of ageing rooftop solar projects and the implementation of mandatory rooftop solar initiatives.

The Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has outlined comprehensive measures for housing and buildings to achieve carbon neutrality by 2050. According to this plan, 60% of newly constructed detached houses will incorporate solar power generation equipment by 2030. Looking further ahead, by 2050, it will be common for houses and buildings that are rational to have solar power generation equipment.

In a significant move, starting in 2025, companies engaged in the construction of buildings exceeding 20,000 square meters annually will be obligated to install rooftop solar systems. Kyoto has been at the forefront of this mandatory push for rooftop solar systems. Since April 2020, it has been compulsory for buildings in Kyoto with a total floor area of 2,000 square meters or more to incorporate renewable energy equipment, such as solar power generation. This mandate was further expanded in April 2021 to include buildings with a total floor area of 300 square metres or more. Consequently, with these regulations in place, the expansion of rooftop solar installations is anticipated to gain further momentum.

As of the end of 2023, rooftop solar accounted for nearly half of Japan's cumulative 107.31GW installed solar PV capacity. When compared to other Asian nations, Japan boasts one of the highest ratios of rooftop solar to solar PV capacity. This trend is promising for renewable energy in Japan, especially as solar panel installations on land face constraints related to land scarcity and decreasing subsidies.

Out of Japan's currently installed rooftop solar capacity, 47.7GW, or about 80%, is designated for commercial and industrial (C&I) use, with the remainder allocated for residential use. However, the government has set higher FiT prices for residential rooftop solar to incentivise further growth. The current FiT price for residential solar is JPY16 (US$0.1088) per kilowatt hour (kWh), while for C&I it is JPY10 per kWh. However, the FiT rate for residential rooftop solar is gradually decreasing, having initially been set at JPY39 per kWh. Therefore, installing rooftop solar panels sooner rather than later on residential properties is advisable to maximise profit margins for residents.

Solar curtailments

Despite a positive upward trend in rooftop and utility solar PV installations in recent years, 2023 marked a record for renewable curtailments in Japan, with solar curtailments increasing five-fold. A total of 1.63 terawatt-hours (TWh) of solar output was curtailed in the 11 months to 30 November 2023, compared to 0.29TWh over the same period in 2022. This led to revenue losses of between US$110 million and US$150 million for solar assets. The losses are significant for developers in Kyushu and Chugoku, as seen from the curtailment trends in the following figure.

As a countermeasure in the wider renewable energy market, Japan has amended the order in which solar and wind projects dispatch power to the grid. This move is designed to reduce revenue losses due to curtailment issues. The new 're-dispatch method (certain order)' rule, unveiled on 28 December 2023, replaces the 'first come, first serve' method, which gave existing thermal plant priority over renewable energy sources during periods of grid congestion.

The change is expected to save the renewable power industry between US$120 million and US$150 million in curtailment-related revenue losses. From January to November 2023, Kyushu province experienced a 12.36% curtailment rate for solar, with Chugoku province seeing curtailments of 5.1% for solar over the same period.

Under the new re-dispatch method, METI will prioritise renewables with low emissions and low marginal costs. The move also expands the scope of output control for both firm and non-firm connections (Figure 8). The changes to dispatch order rules are positive for the renewables industry, which has seen new capacity additions growing faster than transmission line capacity growth. However, the impact the new dispatch rule will have on power prices in Japan remains to be seen, though we anticipate it will lead to greater volatility in spot power prices in the long term.

Battery energy storage systems

With the introduction of the FiP system and the increasing problem of curtailments, battery energy storage systems (BESS) have become a promising solution for businesses. Over the past year, seven battery projects, with a combined capacity of 358MW, have been launched. They have been primarily for wind projects that have completed their FiT subsidy term or offshore wind farms that want to store energy and sell it in the market through FiP for further profit during peak hours. The FiP scheme is gaining momentum,

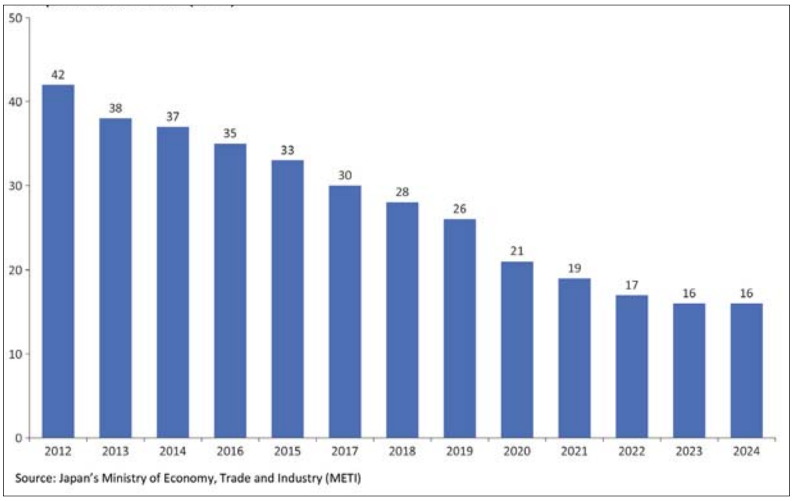

Figure 5. Residential rooftop solar FiT price over the years, JPY per kWh

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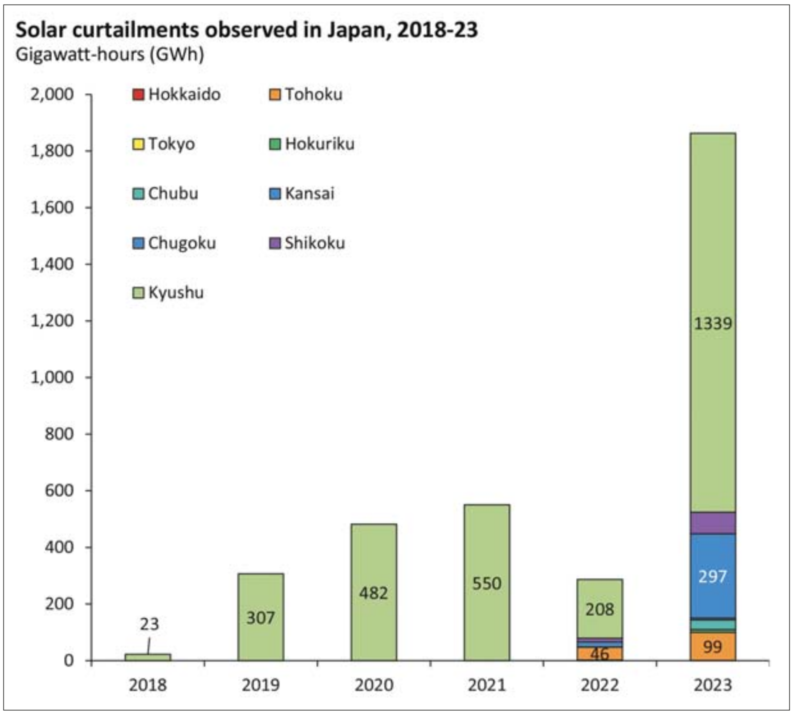


Figure 6. Curtailment trends observed in Japan, 2018-2023

Sources: Rystad Energy Renewables and Power Solution; Renewable Energy Institute, Japan

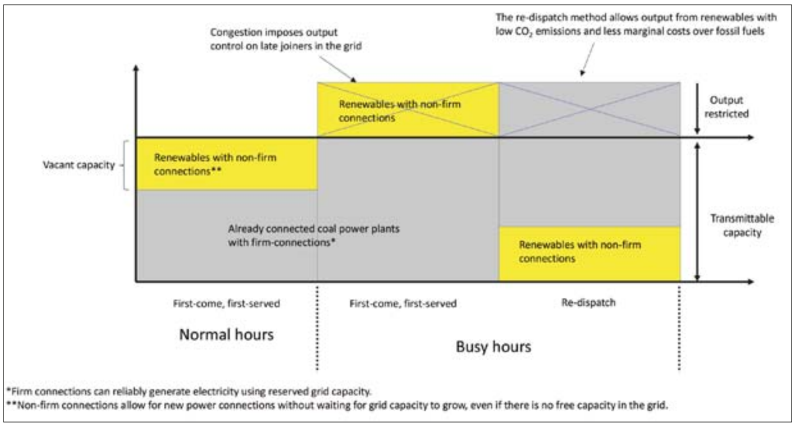
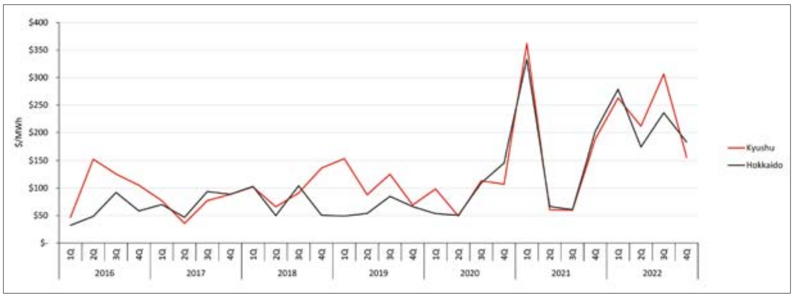


Figure 7. Japan's output control methods, first-come-first-served versus the new re-dispatch rule

Sources: Japan's Agency for Natural Resources (ANRE); Japan's Ministry of Economy, Trade and Industry (METI)

and BESS is becoming increasingly popular for revenue generation through the energy arbitrage market. By charging during the lowest-priced interval of the day (24-hour period) and discharging during the highest-priced interval of the day,



Source: Rystad Energy World Volatile Electricity Market Report

Figure 8. Average one-hour intraday spread

companies can generate revenue while contributing to the reduction of energy waste. Figure 9 illustrates the average one-hour intraday spread of Hokkaido and Kyushu, two prefectures that export a significant amount of electricity and have a high penetration of solar PV. The combination of high solar penetration leading to low daytime prices and high gas prices causing high evening peak prices means Japan is a highly prospective market for batteries. With battery storage, companies can optimise their energy usage while promoting sustainability and contributing to the reduction of energy waste.

Final thoughts

It appears that Japan is making significant strides towards achieving its 2030 goal of having 36-38% of renewables in its power mix, including the goal of 14-16% of solar PV. This is largely due to its strategic planning and substantial government support. As a result, Japan's energy security and self-sufficiency are improving. The implementation of subsidy strategies such as FiT and FiP has contributed to the growth of solar PV, although its growth has become stagnant recently. However, rooftop solar is showing promise, and the government's plan to make it mandatory for new buildings is expected to considerably help the country hit its renewable target. Despite the challenge of curtailment that comes with a large penetration of solar, the FiP scheme is opening a good market for BESS business in Japan. According to our analysis, BESS has the potential to generate significant revenue through the energy arbitrage market.

Japan's energy future appears promising, thanks to significant government efforts. While some challenges may arise along the way, the continued support for innovative solutions such as BESS and rooftop solar is crucial. These measures will not only help address challenges but also create new business opportunities in the market. ■

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How solar PV is taking on wind in the MISO territory

Transmission | Covering 15 states, the MISO area is one of the largest transmission networks in the US, yet solar and storage have had a battle to gain recognition in the territory. Jonathan Tourino Jacobo reports on recent progress as well as the ongoing regulatory obstacles still holding deployment of the technologies back

Credit: Adapture Renewables

The 6.6MWdc Lemond Solar Center project in Owatonna, Minnesota. The MISO territory is one of the world's largest energy markets

Regular readers of *PV Tech* might have noticed a recent increase in our coverage of solar projects in the Midcontinent Independent System Operator (MISO) territory in the US. Obviously, the fact that it is the largest regional transmission organisation (RTO) in the US by geography and one of the largest independent system operators (ISO), covering 15 states stretching from Louisiana up to Canada, is a helping factor for the increased activity in solar PV. MISO covers nearly 75,000 miles of high-voltage transmission and has 191GW of installed generation capacity, as of December 2023, according to MISO's website.

Even if solar PV is not necessarily the dominating renewable energy across the region in terms of current installed capacity, with wind representing a share of 16% of all resources against PV's 4%, solar is fast expanding. The potential growth of solar PV in the coming years could be easily shown through the backlog of capacity that is waiting at the interconnection queue in MISO.

"MISO has historically had an annual cluster process, where every year there's a new cluster of projects that are trying to apply to inject power on the grid. In 2021, the cluster was 66GW, which was more than double 2020. And in 2022, the cluster was 170GW. That's not solar only, but over half of the active queue right now in MISO is solar," explains Gabriel Klooster, director of development at solar and energy storage developer, Adapture Renewables.

With increased competition looming in the MISO territory and with more and more solar PV capacity waiting for grid connection, Klooster says: "It's easy to feel we're late to the game. It's really difficult to start now with solar development projects and say, they might not come online until 2029-2030, with the MISO delays."

However, a recent decision from the Federal Energy Regulatory Commission (FERC) rejected MISO's MW cap requirement to manage the size of the queue in 2023 and needs to open the window again, in a win for renewables.

PV development booming in wind-led states

Solar PV is the clear leader in that field with over 120GW waiting for transmission access as of October 2023, according to data from Sustainable FERC Project. And that's without adding an extra 40GW of solar-plus-storage capacity in the queue, also as of October 2023.

The problem with that is that it also makes it one of, if not the, biggest challenge to develop a solar project in that territory, says Klooster. "It's in a very high level of competition."

Klooster explains how five years ago the picture was very different, giving the example of farmers not considering having solar PV in their fields five years ago, but are being flooded with opportunities from numerous developers. "I recently spoke to a farmer in Illinois, who had received over 30 mailers from different solar companies. The number of solar development companies who are in that space right now is just booming," says Klooster.

In states such as Iowa, where wind has been the primary driver for renewable energy growth, solar has seen growth too, boosted thanks to utility-scale projects, explains Klooster. Up until 2020, the state added less than 50MW of solar capacity per year, and now has added more than 150MW between 2020 and 2022, according to data from trade association the Solar Energy Industries Association (SEIA), which expects the state to add nearly 2GW of solar PV over the next five years.

Interest in solar from Louisiana to Minnesota

Klooster says that he expects solar to boom in all the states covered by MISO. "Arkansas is one in particular that didn't have a ton of solar investment a few years ago. If you look at the MISO queue data, it has just exploded in terms of the number of solar projects that are at least applying to be put on that grid," explains Klooster, adding that Adapture Renewables has faced competition from Mississippi to Minnesota.

"It's really important to say, though, that five years ago, solar in MISO was a risky bet. Only some of the smaller, less risk-averse developers or even bigger ones that focus on kind of the bleeding edge, were starting to develop solar there five years ago," says Jesse Tippett, VP of power marketing origination at Adapture Renewables.

As markets such as PJM (Pennsylvania, New Jersey and Maryland) or California ISO (CAISO) started to get saturated in solar projects, developers looked at other regions to build solar capacity, adds Tippett, with MISO among the more interesting ones due to its size. The same goes for off-takers looking at new regions to do solar transactions.

In terms of the development of a solar project, MISO's topography also plays in its favour when building a PV plant there. "One aspect of MISO in particular is the geographic realities. There's a lot of flat farmland in MISO," says Klooster, adding that it is less populated and has fewer population centres than PJM, for instance.

Even though some differences might occur between states, especially in terms of permitting, with Minnesota having a state permit process, the interest is the same across all the territory for landowners, explains Klooster.

"Local utilities are offsetting or replacing their fossil generation fleet with renewable energy. So there's a lot of opportunity from north to south with local utilities," adds Tippett. Corporate off-takers, on the other hand, are looking into "the dynamics of the transmission infrastructure, to see where it makes the most sense to buy the energy and then deliver the energy through the MISO system".

MISO's ancillary ban on renewables

Despite the ever-increasing interest in solar PV from Louisiana to Minnesota from developers and investors alike, the RTO/ISO has not yet fully embraced renewables on all fronts. One of the ongoing issues between renewables and the MISO territory is the latter's ban on dispatchable intermittent resources – solar, wind and hybrid battery storage – to provide ancillary services. The move prompted nonprofit, Earthjustice, to file a Section 206 complaint – an administrative complaint – with the Federal Energy Regulatory Commission (FERC) in 2023 on behalf of the SEIA.

The issue of the ban was because MISO codified it in its tariff, and was deemed "unjust and unreasonable", explains Aaron Stemplewicz, senior attorney at Earthjustice. "The reason why we believe that was because there's a lot of technical data out there showing that these resources are fully technically capable of providing ancillary services."

Studies in CAISO, for example, showed that wind and solar could successfully provide ancillary services, while other smaller balancing areas have also demonstrated that wind can successfully provide ancillary services, adds Stemplewicz.

In the end, FERC rejected Earthjustice's complaint late in 2023 and upheld MISO's ban. It did acknowledge the technical capabilities of renewable resources to provide ancillary services; however FERC argued that the times when it would be most profitable for renewables to supply ancillary services, they would not be able to deliver the power because they would be behind transmission constraints. "In other words, the power from the renewables would not be able to get to where they needed to go," Stemplewicz says. "That being said, I would not concede that renewables (particularly solar) would never be profitable or are always behind these constraints."

Stemplewicz highlights that this could delay the use of renewables – solar, wind and hybrid storage – as ancillary services when actually needed, as it would be necessary to file another complaint.

Although not all renewables are banned from providing ancillary services, standalone battery storage is still able to participate in the ancillary service, despite hybrid making more financial sense. "It's more likely that hybrids are going to be the ones participating in the ancillary services space, based on the research that we have found. They're more likely to more easily make revenue than standalone wind or solar for ancillary services," explains Stemplewicz.

Forward-thinking on ancillary services

Even though ancillary services are not a big financial market at the moment, Stemplewicz says that the lawsuit was brought as a forward-thinking one as ancillary services for renewables can become more important and more profitable in the future, with the mix of available resources changing in the coming years.

Even though the decision FERC made last year was not the one Earthjustice expected, it still left the door open to submit a new challenge in the future. Once renewables are no longer behind congestion restraints and are widely available to provide ancillary services, it would set the stage for the next step, says Stemplewicz.

"At that time, we would need to re-file the complaint in sort of an as-applied challenge and say, 'Okay, you wanted us to wait until it's profitable, it is now profitable'. You've already said they're capable. You were just waiting for a point in which the congestion is relieved such that these renewables can provide these services, then bring the [Section] 206, then presumably we will get a favourable ruling."

"I fear that the approach FERC has taken here is that when these ancillary services are needed, and when they're capable of getting on the system, we're going to have a delay now to get Section 206 filed to get new tariff language hammered out in the stakeholder process. We might be in a place where we need these ancillary services from these resources, but we're not getting them because of an administrative delay," adds Stemplewicz.

Similarly, projects are unlikely to become financially unviable due to the lack of participation in the ancillary service at this stage and the value of the ancillary service market, yet it could change in the future.

Stemplewicz explains that Earthjustice filed a complaint with the MISO territory as it was the only RTO or ISO to have an explicit ban written into the tariff stating dispatchable renewable sources cannot participate in providing ancillary services, adding: "Other RTOs or ISOs might have a sort of tacit ban or operating requirements that make it impossible for a wind, solar or hybrid resource to participate in that market."

With the Inflation Reduction helping accelerate the interest and growth of renewables across the entire country and MISO investing more than US$10 billion in 18 transmission projects in 2022 – the first in a four-tranche transmission planning process – that would support 53GW of new renewable energy resources, Stemplewicz expects a lot of renewables to come online as well as more transmission lines. ■

Growth in the face of war: Building solar in Ukraine

Market update | Despite Ukraine's ongoing conflict with Russia, the country's solar sector continues to develop. Lena Dias Martins reports on the opportunities solar developers are finding amid the horrors of war

Installed renewable capacity in Ukraine is growing. This was the message from Maksym Sysoiev, partner at global law firm Dentons, at the 'Large Scale Solar Summit Central Eastern Europe' (LSS CEE) late last year, hosted by *PV Tech Power* publisher, Solar Media. "Despite the odds," Sysoiev added, new solar plants are being implemented and completed.

Although the precise installed capacity of solar and other technologies in Ukraine is now considered restricted information, the country's renewables sector is growing, as memorably illustrated by *The Guardian* last May, which revealed that Ukraine had built more onshore wind turbines since Russia invaded Ukraine in February 2022 than the UK.

Addressing the Energy Security Forum 2024 in February, Andrii Gerus, the chairman of the committee on energy, housing and utilities, revealed that Ukraine commissioned roughly 500MW of solar power plants over the year, noting that renewable generation "significantly helps to ensure the stable operation of the power system".

"I also believe that 2024 will be a year of investment and launch of energy storage facilities. I think we will not see isolated cases, as it was before, but a number of interesting and useful projects for the energy system," added Gerus.

Facilitating this "year of investment" will require demonstrations of security and stability to entice investors, a tough demand for a country amid conflict. But Ukraine refuses to be held back, amending and creating green policies to incentivise international investors to fund Ukrainian renewables, not only for energy security in Ukraine but for the possibility of export.

As Sysoiev's fellow panellist, Kyryll Kostyria, head of legal department at UDP Renewables, noted, "60% of [Ukraine's] renewables are solar, so the possibility to build large-scale solar for export is great."

The Gnatkiv solar farm, one of Rengy Development's Ukraine project portfolio

'Green tariff' vs merchant market

Most solar projects currently operating in Ukraine are under the country's feed-in-tariff (FiT) scheme, says Narek Harutyunyan, CEO and founder of independent power producer (IPP), Rengy Development, a fellow Ukraine panellist at LSS CEE who later spoke to *PV Tech Power*.

Known as 'the green tariff' this policy was introduced in 2009, providing a guaranteed tariff and off-take price (set by the regulator National Energy and Utilities Commission (NEURC)) for energy generated by renewable assets until 2030.

In short, energy produced by renewable assets under the green tariff will be sold to the state enterprise Guaranteed Buyer who will then sell electricity on the market via electricity auctions.

According to Ukrainian law firm DLF, however, the arrears from the green tariff, caused by an accumulation of debts between market participants, threaten the Ukrainian renewable energy sector.

As the last performance report for the Guaranteed Buyer dates back to 2019 (and the last financial statements to 2021), DLF says it's difficult to estimate the precise amount of debt currently owed to producers under the tariff but the organisation estimates that it accumulates to roughly UAH30 billion (US$79 million).

Alongside market and regulatory factors, Harutyunyan attributes this debt to a "significant decrease" in electricity consumption in eastern regions, causing supply and demand economics to become "skewed".

"This is one of the reasons many solar power plant investors (old or new) are planning to switch to either merchant-based schemes or even find options for corporate power purchase agreements (CPPAs)," continues Harutyunyan. "Both routes are very new for Ukraine, so it may take some time for them to be bankable."

However, Harutyunyan notes that Rengy is currently in the process of launching a CPPA-based project to "tick the boxes from both regulatory as well as bankability points of view and be able to offer and expand this direction going forward".

July 2023 saw Ukraine sign into law a groundbreaking piece of green legislation: 'On Amendments to Some Laws of Ukraine Regarding the Restoration and Green Transformation of the Energy System of Ukraine (Law No. 3220).'

This law implements a number of beneficial instruments for renewable energy bankability, including confirming the preservation of the green tariff to provide stability for assets already under the scheme, as well as introducing a contracts for difference (CfD)-like scheme that allows producers to minimise their susceptibility to price volatility in the electricity market.

Harutyunyan says the law will have a "significant impact", allowing "many issues to be resolved and new opportunities to be introduced".

For example, Harutyunyan points out that the law allows power plants to exit the FiT scheme and sell electricity to the market, either independently or via other traders, simply needing to invoice the difference between the market price and initial FiT to the Guaranteed Buyer.

The law also proposes the introduction of guarantees of origin for electricity which Harutyunyan hopes will be a catalyst to building a market to trade these certificates either domestically or in Europe.

During the LSS CEE panel Kostyria pointed out that although this market may not make a significant impact domestically, it will be helpful for energy trading internationally.

"What we see now when we talk to international companies is that they ask us to provide certificates of origin, as they need to provide this for their internal audit to show that they are carbon neutral," said Kostyria, adding: "Of course, for exporting electricity, those certificates of origin are very important because, as far as I understand, the EU is expecting [Ukraine] to only export renewable energy and to confirm this, these certificates are very important."

Moreover, Harutyunyan notes that the law allows active consumers to develop renewable power plants for their own use with the option to sell surplus electricity to the market or grid.

Sysoiev also praised the introduction of the "active consumer in Ukraine" during the panel last November. Although this mechanism would require secondary legislation before it can be used, it would allow 50% of purchased electricity to be sold to the grid whilst the remaining amount is consumed. "I can confirm that my clients are considering this mechanism," Sysoiev revealed.

Other benefits include an exemption from the requirement for a licence to supply electricity for assets under 5MW capacity and no distribution or transmission charges related to internal consumption. "We see the interest is there and active consumers will develop in Ukraine," added Sysoiev.

Rengy's Afanasivka PV plant in March 2020 (top) and February 2024 (bottom), following Russia's invasion of Ukraine

Credit: Rengy Development

Occupation and destruction

The promise of growth in solar does not diminish Ukraine's status as a country at war.

A stark reminder of this came during LSS CEE when Dr Stanislav Ignatiev, head of the council at the Ukrainian Association of Renewable Energy, was forced to exit the Ukraine panel early, (which he was joining remotely from Kyiv) due to an air raid siren.

The conflict has inevitably affected Ukraine's current and planned solar capacity as developers face the threat of having their assets occupied or destroyed.

Speaking at LSS CEE, Kostyria revealed that roughly half of UDP Renewables' operational PV plants are currently occupied, whilst fellow panellist Harutyunyan estimated that Ukraine currently has 6GW of nuclear and 2GW of renewables occupied, making up roughly 25% of the country's total capacity.

Elaborating on this, Harutyunyan tells *PV Tech Power* that Rengy is currently re-building its 13MW solar plant located close to a war zone that was previously occupied and "practically destroyed" by the Russian army.

"It has been reoccupied since, and we decided to restore it not only to recover some of our income flow (it is under the FiT scheme until 2030) but also to help deal with the lack of electricity in the country, especially in remote regions," adds Harutyunyan.

Destruction is not an exclusive threat to renewable and low-carbon assets however, as the central generating capacity in Ukraine has also become a target. This makes the ability for industrial customers to set up individual generating capacities – set out in the green tariff – even more critical for the country's energy security.

Why build in Ukraine?

With the threat of destruction looming over renewable assets and network infrastructure, it's worth considering the reasoning behind building new solar capacity in Ukraine.

"I believe there are different reasons for building new plants," Harutyunyan says before proceeding to give *PV Tech Power* four split into two categories: energy security and export opportunities.

Harutyunyan's first three reasons for building solar in Ukraine relate to energy security:

- Helping the country cope with electricity deficits caused by asset destruction.
- Decentralise generation by building multiple smaller/medium-scale projects that are safer to operate and harder to attack.
- Supplying specific large industrial consumers with a stable supply of electricity at predictable prices.

Meeting future demand is also a consideration; as mentioned during the Ukraine panel, demand in Ukraine has decreased by 20% as citizens leave the country. However, this demand will return and need to be met, requiring the "significant" amount of destroyed or incapacitated fossil fuel-based electricity capacity to be replaced, Harutyunyan told LSS CEE.

"The country plans to build new nuclear and predominantly renewable capacity, and within the renewable segment, the fastest and easiest to deploy capacity would be solar," continued Harutyunyan.

Another incentive to build solar in Ukraine comes in the form of export opportunities. This was realised in December 2023 when the European Network of Transmission System Operators for Electricity (ENTSO-E) agreed that as of 1 January 2024 the Ukrainian power system operator will become its 40th member.

Harutyunyan tells *PV Tech Power* that neighbouring countries may be inclined to "bet" on this recent integration as "grid infrastructure and land are more available in Ukraine than in bordering EU countries, [so] investors may want to invest in solar-export oriented projects".

Kostyria echoed the benefits of the opportunity to export energy from Ukraine during the LSS CEE panel: "We see the need for Ukrainian energy to be exported to enable international investors to come into Ukraine and provide more stability," said Kostyria, adding that cross-border PPAs would be a fantastic way of enabling this.

Solar is an attractive candidate for exporting energy, continued Kostyria; aside from 60% of the country's renewable capacity being solar, Ukraine, as a large country geographically, has plenty of land on which to build large solar plants.

The introduction of the EU Carbon Border Adjustment Mechanism (discussed on pages 74 & 78) could also stimulate solar growth in Ukraine, as more Ukrainian goods producers will be looking at developing a cleaner, consumed electricity mix to avoid higher carbon taxes.

As Kostyria concludes: "The possibility to build solar for export [in Ukraine] is a really great opportunity." ■

A "tsunami" of commercial and industrial investment: trends in African solar power in 2023

Market update | The potential of solar power in Africa is beginning to be realised, with 2023 seeing record levels of deployment. JP Casey explores some of the latest trends shaping the continent's solar sector, where the C&I segment in particular is surging ahead

Credit: Syrah Resources

C&I installations have surged in Africa, such as this one in Mozambique by CrossBoundary Energy

Much has been made of the potential for the solar sector across Africa, not least because of the region's considerable solar reserves and pressing demand for electrification. According to the International Renewable Energy Agency (IRENA), in 2021, high levels of sunlight in Africa meant that it accounted for 40% of the world's solar power generation potential but generated just 1.48% of its electricity from solar sources.

African countries are also among some of the most likely to experience a spike in energy demand in the coming years. In 2022, the International Energy Agency (IEA) reported that between 2020 and 2030, Africa is likely to see its energy demand jump by a third, putting pressure on the continent's governments to expand their power-generation facilities.

With this in mind, the most recent edition of the Africa Solar Industry Association's (AFSIA) annual report on the state of the continent's solar sector makes for some encouraging reading. In 2023, Africa added 3.7GW of new solar capacity in 2023, a record figure. This marks four consecutive years of growth in the African solar sector, from 0.9GW of capacity additions in 2020 to 1.1GW in 2021 and 3.1GW in 2022, and suggests that there is interest both in agreeing to build, and actually breaking ground, on new solar projects in the continent.

However, with many of the obvious challenges present for such a rapidly developing power sector, including the resilience of local power grids and the ability of various governments to effectively regulate this rapidly changing energy mix, continuing this streak of record capacity additions, and building a resilient renewables sector for Africa as a whole, loom large as challenges for the future.

South Africa dominates capacity installations

Perhaps the most striking aspect of the African solar sector is the extent to which South Africa dominates the industry. In 2023, AFSIA notes that South Africa added 2.9GW of new solar capacity, pushing its total installed solar capacity above 7GW. This figure accounts for close to half of Africa's total installed solar capacity.

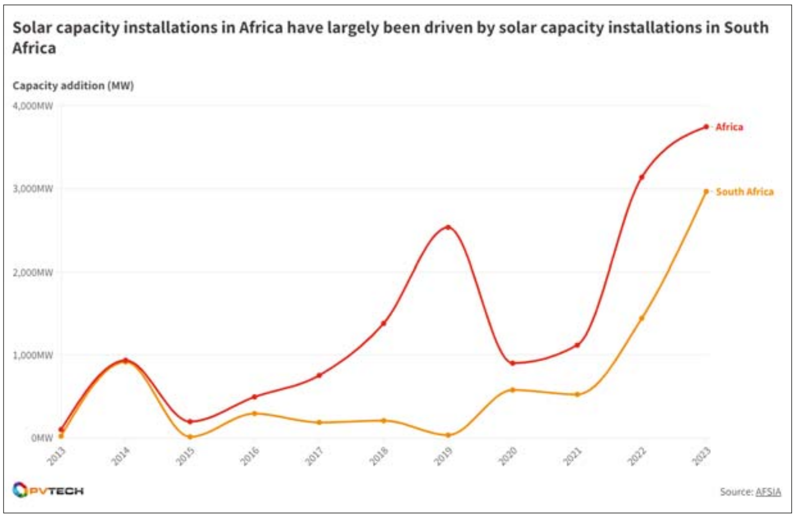
"We're seeing a lot of growth, especially across the largest economies, such as South Africa and Kenya," says James Shoetan, chief commercial officer at CrossBoundary Energy, a renewable energy developer based in Kenya with projects across a number of African markets.

This emphasis on larger markets explains much of the interest in the South African solar sector in particular, as this is a country with significant renewable power targets and robust legislation that aims to encourage investment in new clean power projects. The South African government released its Integrated Resource Plan, setting out a framework for the country's energy mix, in 2010, and the following year, new definitions for power purchase agreements and independent power producers were passed, vital steps in encouraging large-scale private investment into the South African solar sector.

"A lot of this is driven by strong solar radiation, electricity supply and cost dynamics, of which the latter tends to be the biggest driver," says Shoetan, who adds that, in South Africa, there is a business case for many of these investments. "We have seen that, with solar, you can compete with the vast majority of grid prices in Africa because some of them are really high."

South Africa also has an outsized impact on the rest of the African solar sector, as the more mature status of its market means other countries' sectors are often following in its wake.

"In South Africa, which saw more than



Source: AFSIA

Figure 1. PV installations in South Africa versus the rest of the continent, 2013-2023

2GW of new commercial and industrial (C&I) capacity installed in 2023, C&I is embraced by the entire economy as a result of load-shedding, which is plaguing the country," says John van Zuylen, AFSIA CEO, whose organisation's report draws strong parallels between South Africa individually and the African solar sector as a whole. "Hundreds of businesses have had no other choice but switch to solar to continue their operations."

This relationship is perhaps the clearest in terms of capacity additions. As the graph in Figure 1 demonstrates, using AFSIA figures, save for a three-year period in the late 2010s, South Africa's capacity additions have been the driving force behind capacity additions in the whole of Africa, to the point where, in 2023, South Africa accounted for more than 75% of the continent's newly installed solar capacity.

Grid challenges in South Africa

However, this is not to say that the South African solar sector is not without challenges that will need to be overcome for both the benefit of South Africa, and the rest of the African solar sector, which will look to follow in its footsteps.

A key challenge is one of scale, and expanding the solar sector from one that accounts for a small portion of the country's energy mix to one that is making a significant contribution to South African power.

According to the US International Trade Administration, as of 2023, 80% of South Africa's energy demands were still met by coal-fired power plants, and addressing these macro challenges for the sector, from reducing reliance on fossil fuel generation to building the necessary grid infrastructure for renewables to take their place, hang over the industry.

"The main question is to see at what speed these grid improvements and large-scale projects can be developed and built, while on the other side C&I gets cheaper every day and can be installed very rapidly," says Van Zuylen, pointing out that, while solar is an attractive investment, scaling up solar will have to be done quickly and effectively.

Solar in the mix

Beyond South Africa, both Shoetan and Van Zuylen suggest that solar could form part of a more diverse energy mix for the entire continent. This approach could reduce the stress on the solar sector in particular, as solar developers are not put in a position where they are expected to make up for the entirety of Africa's lost fossil fuel generation capacity, but just one part of a more diverse energy mix.

"What I think is that you will see some wind," says Shoetan. "We're also doing wind, where it makes sense. One of our coolest projects is for Rio Tinto in Madagascar; what we're doing [is] wind plus solar plus batteries, all integrated with their existing generator fleet, to bring them up to 70% renewable contribution in the future."

Thanks to new and efficient storage solutions, there is indeed hope that large-scale solar-plus-storage plants can be built across the continent in the near future," agrees Van Zuylen. "Without storage, it would be practically impossible to add a consequent number of large-scale solar projects in most African countries because of the weakness of the transmission and distribution grid. But storage can remedy this problem for the main part."

Van Zuylen also suggests that many of the off-grid benefits of solar investment in South Africa are applicable to Africa more broadly, with solar an opportunity for those in countries with less developed grid infrastructure to help meet energy demand. Off-grid power supply has seen considerable domestic and international interest in recent years, with the World Bank estimating that, between 2000 and 2023, the number of mini-grids in operation across Africa has increased from 500 to 3,000.

Similarly, projects such as the European Investment Bank and ENGIE's Energy Access programme, and the USAID's Power Africa initiative, look to draw international investment towards new power programmes in Africa.

"Several regional power pools have also made significant progress recently, most notably in West Africa," explains Van Zuylen. "These power pools also act as some form of grid-stabilising storage and for a better distribution of generation and consumption across the entire connected grid, therefore creating opportunities for new large-scale solar projects."

Yet not all markets can benefit from investment in the same power generation sources, with Shoetan noting that, in the case of grid infrastructure, different countries could benefit from additional funding for their grids, versus battery facilities.

"When you have a strong grid, it doesn't make as much sense to have batteries," says Shoetan. "So, for instance, you'll see, in Kenya, there aren't a lot of businesses with big batteries because the grid is pretty strong."

Growth of C&I and residential

The diversity of the African energy mix is perhaps most apparent in the breakdown of the continent's solar sector. AFSIA figures note that, in 2023, 65% of new capacity additions were made in the C&I sector, mirroring the sector's growth in South Africa, and continuing a trend seen in recent years. In 2022, the C&I sector added 1.6GW of new capacity, compared to 1.4GW for utility-scale deployments, and this difference jumped in 2023, with the C&I sector adding 2.4GW of new capacity, compared to just 1.2GW of utility-scale capacity.

"Based on solar projects info collected by AFSIA for projects since 2006 in Africa, there has been a phenomenal evolution of the C&I segment in Africa," explains Van Zuylen. "For many years, C&I was barely existent as large-scale grid-connected projects were the norm in Africa.

"But since 2017, C&I started to grow and represent a real niche market on its own. And in 2022, C&I even became more important than large-scale across the continent, driven mostly by the tsunami of C&I installations in South Africa as a result of the load-shedding crisis."

This "tsunami", as Van Zuylen puts it, comes at a time where interest in other sectors, notably, utility-scale, is cooling. According to Shoetan, the fact that utility-scale projects often require developers to work with national governments makes such projects less enticing for these developers.

"Utility-scale involves government entities…we find can move slowly and they have a lot of levels and bureaucracy to move through," says Shoetan. "Also, a lot of these are project financed, which also require you to get a shovel-ready project, and then shop it around to different investors who then have feedback on that project because it's not quite shovel-ready, and so you have this back-and-forth."

However, the African solar sector is likely to include a combination of utility-scale projects and the booming C&I segment, with Shoetan suggesting that utility-scale will continue to play a key role in the sector.

"Every single piece has a part to play," Shoetan says. "Utility-scale? We still see that happening. We'll see C&I, which generally start [with] smaller [capacity], start to catch up in some of those places now that people are seeing that it's viable [and] people are doing it."

The graph in Figure 2 demonstrates how, while C&I installations have grown considerably in recent years, they are not singularly responsible for new capacity additions in Africa, and the sector is as diverse as Shoetan expects. According to AFSIA figures, between 2022 and 2023, the African mini-grid sector's annual capacity additions increased from 7.1MW to 11.7MW, while its solar home system capacity increased from 86.9MW to 90MW.

Africa as an investment destination

The growth of the C&I sector in particular is demonstrative of Africa as an attractive investment destination, according to Van Zuylen, who says that a demand for electricity is driving much of this transition.

"For starters, it is the overall poor service level of African utilities and grids which is creating this need," begins Van Zuylen. "Businesses need electricity to operate. Most of them would prefer to work with a reliable national utility providing a regular electricity supply. But in the absence thereof, these businesses accept the imperfect situation or rely on diesel generators when the cost is viable, for example, when diesel is subsidised."

But the falling cost of solar is now making it particularly attractive to businesses. This is echoed by a number of research organisations. The International Energy Agency (IEA), for example, notes in its latest forecasts that the cost of generating electricity from solar sources in Africa is expected to be as low as US$18-49/MWh by 2030, compared to US$33-86/MWh for onshore wind and US$30-110/MWh for gas, making solar investments attractive for developers, and solar power enticing for buyers.

"This trend is further amplified by a growing offering of financing solutions, which remove the barrier of the initial solar capex, as well as the notable example of Nigeria where the fuel subsidy has recently been removed, thereby revealing to the wider public the true cost of diesel kilowatt-hours and the fact that solar is in many cases the more economically viable option," adds Van Zuylen.

"We've been the first company to get licences to sell power privately across Ghana, Kenya, Sierra Leone [and] Somalia," adds Shoetan, also pointing to specific jurisdictions where there is potential for new solar investment. "We leverage those licensing frameworks, that we've helped develop for the regulatory bodies, to help other countries apply those as well."

Learning from other countries

Operating in a region as diverse as Africa poses challenges for actors across the solar sector, but Shoetan is optimistic that his company's work in one region could inform work in other countries, creating the opportunity for developers in one area to learn from those in others.

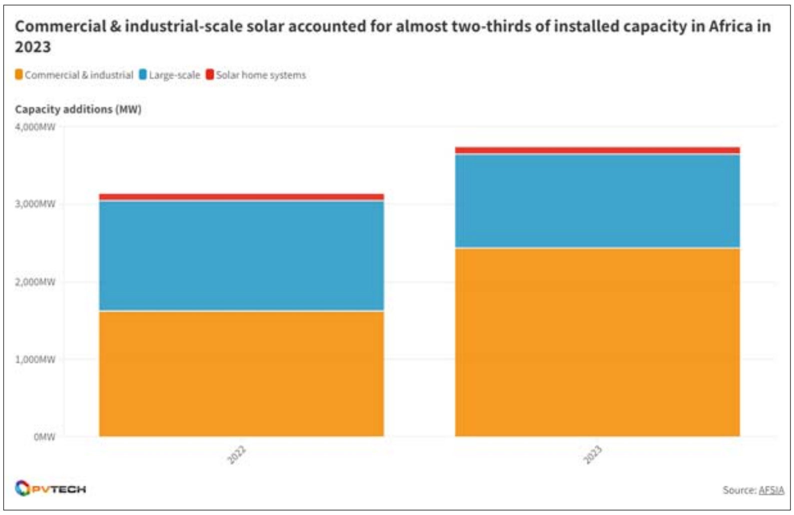
"Drawing from our experiences on working with Ghana [and] Kenya across their licensing regimes, I think it was quite helpful there," says Shoetan. "I think the technology is quite ubiquitous these days, it's just more about the cost curve coming down and down and down. From a technology standpoint, it's not really that different, [but] from a delivery standpoint, it's very different."

Shoetan notes that this desire to improve, and learn from other work, could be of benefit to solar developers themselves. He described his company's work as having to become more multi-faceted in recent years and that developers need expertise today that they may not have needed in earlier years, creating an opportunity for developers to learn too.

"For us, what we've had to do is develop in-house competencies across just about every single area required to make a renewable energy project happen," says Shoetan. "We've had to build up and invest in our own in-house engineering, development, regulatory, finance [and] legal teams, that allow us to move very quickly."

Ultimately, this could be of benefit for the African solar sector as a whole. There is considerable demand for new solar power, and a range of investors and developers keen to become involved in the sector. Shoetan concludes that the outlook for the African solar sector as a whole is highly encouraging.

"I think for others who are interested, there's definitely loads of room," Shoetan says. "I don't think it's going to get saturated anytime soon, and given the growth, as well, there's definitely a lot to do." ■



Source: AFSIA

Figure 2. Businesses' demand for power is driving a boom in Africa's C&I sector

Product reviews

Module | Sharp Energy Solutions Europe launches bifacial TOPCon module for commercial and utility scale installations

Sharp Energy Solutions Europe has launched its latest bifacial tunnel oxide passivated contact (TOPCon) solar module with a wattage upgrade to 580W.

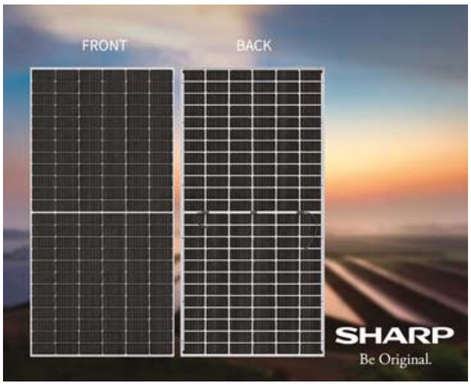
Market & applications:

Ensuring operational efficiency under multiple weather conditions is crucial to prolonging the module's lifespan. The NB-JD580 module measures 2278 x 1134 millimetres and features a 30-millimetre aluminium frame. The front and back glass layers are two millimetres thick, adding up to a total panel weight of 32.5 kilograms. With such mechanical specifications, the module can be used in a wide range of applications, including commercial and utility-scale free-field installations.

Rigorous testing in accordance with international standards has confirmed the module's resilience under challenging conditions. Therefore, the module has been awarded IEC seals (IEC61215 and IEC61730) after passing tests for resistance to ammonia (IEC62716), salt mist (IEC61701), sand and dust (IEC60068), and potential-induced degradation (IEC TS62804).

Industry challenges:

Optimising cell conversion efficiency is an



ongoing aim for the solar industry. As extreme weather events and the accompanying rise in temperatures are getting more frequent, the module is designed with a low temperature coefficient of -0.30%/°C for power output, ensuring outstanding performance even in elevated ambient temperatures.

Technical solution:

The product constitutes a glass/glass solar module incorporating n-type 144 M10 half-cells equipped with 16 busbars. The additional gain of bifacial modules comes from irradiance received on the back of the module, which enables the n-type TOPCon module to have a bifacial ratio of up to 80% and a module efficiency of 22.45%.

The n-type TOPCon technology offers multiple advantages, including increased power and efficiency, improved low-light performance, and elevated bifaciality.

Instead of an opaque backsheet on the back of the module, the back of the module boasts a glass layer that allows light to reach the back of the cells. This additionally generated energy is the main benefit of bifacial technology over monofacial technology.

The higher power and efficiency of the n-type TOPCon technology, coupled with the enhanced low-light performance which ensures the panel continues to produce energy even in sub-optimal lighting conditions, increase the module's overall efficiency.

Unique features & benefits:

The module has been officially recognised and awarded IEC seals. Aside from this, the module is covered by a 30-year linear guarantee on the nominal power output. Within the EU and several other countries, a 15-year product guarantee applies when installed in free-field systems , and this is upgraded to 25 years for rooftop-mounted modules.

Availability:

The module is available now.

Module | Trina Solar rolls out n-type i-TOPCon module for C&I rooftops

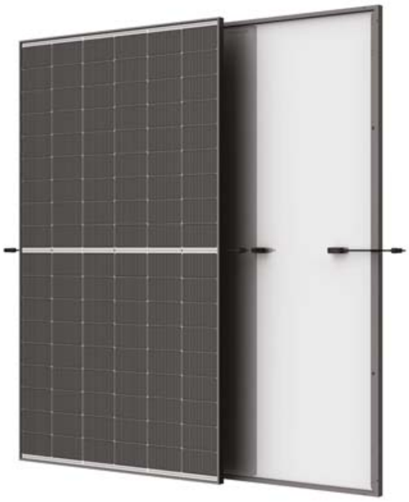
Chinese solar manufacturer Trina Solar has launched a new n-type industrial tunnel oxide passivated contacts (i-TOPCon) module designed for commercial and industrial rooftops.

Market & applications:

Solar modules are increasingly being included by developers in new commercial and industrial buildings to reduce energy consumption and energy costs, while some existing buildings are also adding modules to increase energy efficiency. Trina Solar's latest NEG18R.28 dual-glass module is designed specifically for commercial and industrial rooftops. Measuring 1961 x 1134 millimetres with a frame height of 30 millimetres, the module offers a variety of flexible installation solutions for system deployment, including short side and long side clamping, crossed beam, shared rail and slide-in mounting.

Industry challenges:

While rooftops are a critical part of increasing installed solar capacity, how to install modules on commercial and industrial



rooftops could be a challenge. Trina Solar's module weighs only 23.5 kilograms. This lighter-weight module encompasses 1.6 x 1.6 millimetres thin dual-glass, making installation in hard-to-reach rooftop spaces easier.

Technical solution:

Thanks to its short circuit current of 15.86A, the module, combining n-type technology with 210mm rectangular silicon wafer cell technology, will generate up to 505W power and deliver a high efficiency of 22.7%. The module is also compatible with most mainstream inverters, optimisers and mounting systems on the market. The module boasts a degradation rate of 1% in the first year and a 0.4% annual degradation rate. It can also yield 8.6% more power compared to p-type modules. The module's anti-reflection coating also helps deliver efficiency by reducing reflection and delivering optimum visible light transmission. It also has mechanical loading of up to 5,400 Pa snow load and 2,400 Pa wind load.

Unique features & benefits:

The module is compatible with other balance of system (BOS) components, and mainstream inverters, optimisers and mounting systems on the market. The module uses fewer plastics as it's without a backsheet, thus improving the module's recyclability.

The module's dual glass design also provides increased scratch, crack, and impact resistance, and ensures the module's resistance to salt spray, acids, alkalis, high temperature and humidity.

Availability:

The n-type i-TOPCon module is available now.

Product reviews

Module | AIKO Solar's new n-type ABC modules with two variations

Chinese cell and module manufacturer Aiko Solar has launched the new Stellar series of n-type all back contact (ABC) modules consisting of the Polaris module and the Sirius module.

Market & applications:
The bifacial modules can be deployed in utility-scale operations and are designed to meet the different needs of ground-mounted and offshore or floating solar PV applications.

The Polaris module is designed for mountain and flatland as it addresses the irregular irradiation conditions due to limited land and complex terrains, thanks to the use of power optimisation technology for partial shading conditions.

The Sirius module is designed for mudflat and water surfaces since It incorporates high-resistance water encapsulation technology, anti-corrosion frames, and waterproof cap design, enabling the module to overcome the challenges posed by salt mist and high humidity. This design can also stabilise power generation and performance reliability while reducing cleaning frequency and operation and maintenance costs throughout the module's entire lifecycle.

AIKO Solar says the Stellar series can complement its existing Comet solar modules for commercial and industrial applications and the Neostar series for residential rooftop applications.

Industry challenges:
Increasing cell conversion efficiency is of utmost importance. As a bifacial solar module captures sunlight on both sides, this design boosts power output from a given area and results in an increased levelised cost of energy (LCOE).

Technical solution:
By placing all passivated contacts on the rear side of the panel, ABC modules can have lower parasitic absorption losses than other cells and can appear visually sleeker and cleaner. Both modules are based on the n-type all-back contact (ABC) technology, boasting a bifaciality rating of up to 70% and a conversion efficiency rate of up to 23.7%. The modules boast a wattage of between 620-640W.

Unique features & benefits:
The modules have a temperature coefficient of only -0.26% per degree Celsius at maximum power. Its degradation rate is less than 1% in the first year and no more than 0.35% per year throughout the 30-year power output warranty. All of these metrics have been confirmed by testing completed by TÜV SÜD.

Availability:
The n-type ABC module is available now.

Tracker | PV Hardware launches AxoneDuo Infinity with enhanced flexibility

PV Hardware has launched AxoneDuo Infinity based on the tracker AxoneDuo with multiple system upgrades, capable of enhancing performance on different terrains.

Market & applications:
Renewables play a key role in energy transition and solar is an important part of renewables worldwide. However, the scarcity of suitable land for large scale solar PV plants requires solar developers to operate projects on uneven, if not difficult, terrain. PV Hardware's latest AxoneDuo Infinity can adapt to diverse configurations and meet unique terrain requirements, even within individual projects.

The flexibility of AxoneDuo Infinity reduces the need for significant earthwork, therefore lowering the cost of building and operating a solar PV plant.

Industry challenges:
Uneven terrain requires solar developers to have a better understanding of the site before building a solar PV plan. By using trackers, developers not only can better capture sunlight to enhance the solar plant's efficiency, but also safeguard the modules as trackers can move to a position to minimise the impact of extreme weather events.

Technical solution:
One of the key features of AxoneDuo Infinity is its versatile string interconnectivity that offers a wide range of optimisation options that reduce costs while increasing efficiency. Rows can be independently triggered in its unlinked mode, boosting operational effectiveness.

AxoneDuo Infinity is also equipped with DBox5, an advanced supervisory control and data acquisition (SCADA) system employing sensors, artificial intelligence (AI), and machine learning to monitor installations, pinpoint faults, and anticipate structural threats.

To protect modules, AxoneDuo Infinity's robust weather defence strategy actively positions modules to protect the plant in extreme conditions.

PV Hardware claims that Axone Duo Infinity also has the lowest number of motors and controllers per string on the market, and allows for a large number of combinations to adapt to any configuration: linked or unlinked, with two to four strings per row.

Unique features & benefits:
PV Hardware implements a new manufacturing process which it says can reduce the installation time of solar projects by more than 40%. In the process, the company pre-assembles the most sensitive components within its controlled factory environment before shipping them to a project site, which could reduce the number of components that need to be sent to a site by 85%.

With this manufacturing process, PV Hardware says the tracker guarantees maximum productivity from the start.

Availability:
The tracker is now available.

Tracker | Array Technologies upgrades dual-row solar trackers

Array Technologies has introduced new enhancements to the Array STI H250 solar tracker, offering multiple upgrades including a new transmission system to enhance flexibility.

Market & applications:
Solar trackers are applied on uneven terrain to better capture sunlight. Designed for fragmented terrain and irregular boundaries, prominent slopes and field obstructions, the tracker's enhanced design is based on the legacy product line of H250 which has presence in Europe, South America, and Africa.

Technical solution:
The latest Array STI H250 presents features such as a reduced number of piles per tracker, enhanced tolerance for East-West tilt, and a wider North-South angle between rows. Such features improve suitability for installation in challenging terrains.

Moreover, the enhanced Array STI H250 solar tracker features the transmission system from the Array Technologies' DuraTrack tracker, enabling the removal of the driveline. The slew drives of the tracker can restrict the movement of each row when disconnected, ensuring safe passage for tractors and streamlining maintenance tasks. This feature helps with agriPV as it makes the tracker suitable for dual use alongside grazing animals and crops.

Unique features & benefits:
The tracker can help solar PV plant developers achieve a lower levelised cost of electricity (LCOE) through a dual row design. It uses advanced wireless communication technology to synchronise and control a 60-metre long row with a single motor. Its structure powers about 60 modules per row in a vertical position, meaning that a single motor can move up to 120 modules.

Aside from a new transmission system, the tracker is also capable of integrating into Array SmarTrack energy optimisation software. This functionality enables the tracker to adjust its tilt based on the distinctive features of the terrain, prevailing weather conditions, and the specific geographical location of the installation.

These adjustments are designed to enhance the overall efficiency of a solar PV plant, resulting in an increase in energy capture through the effective optimisation of backtracking and diffuse light strategies.

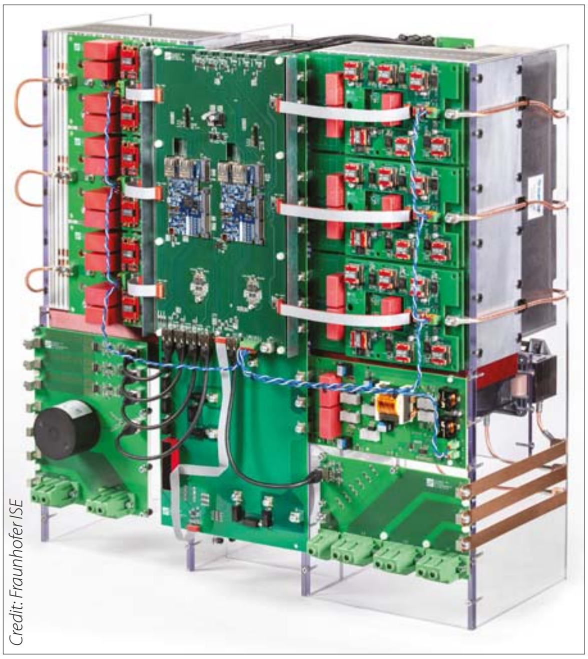
Availability:
The tracker was first showcased in Genera 2024.

On the way to an "all-electric society": Potential for the use of higher voltages in the field of renewable energy

System architecture | In late 2023, researchers at Fraunhofer ISE put into operation the world's first medium-voltage string inverter as part of a project to explore the power electronics for the next generation of large-scale PV power plants. According to the project's leader, Michael Geiss, the signs are looking positive for the introduction of medium voltage in PV

The current climate targets can only be achieved with a step away from fossil fuels to the production and use of renewable energies. This step is also a step towards an "all-electric society". According to the current state of technology, enormous quantities of raw materials are required for this transition. On the one hand, this is necessary to connect a wide variety of consumers and producers to our grids intelligently and with low losses using power electronics. At the same time, however, large quantities of copper and aluminum cables are also required to connect all the components in this grid. The raw materials used must therefore be used as efficiently as possible, as our planet's reserves of raw materials are finite.

One way of saving raw materials is to use higher voltages. With the same power, the current and therefore the required cable cross-section can be reduced. This has long been used in transmission and distribution grids to keep losses low. Especially in the field of utility-scale PV power plants, the use of higher voltages offers enormous savings potential. Figure 1 shows the required expansion of photovoltaics to meet humanity's hunger for energy. By 2050, 63 TW of installed PV capacity will be required worldwide. A technical solution to save materials therefore has a major impact here.



Credit: Fraunhofer ISE

Medium voltage string inverter for future utility-scale PV power plants. Power 250kW, output voltage 1,500V, PV voltage 1.7kV ... 2.4 kV

Motivation for the development towards higher voltage levels

The PV industry is subject to enormous cost pressure. This is one of the reasons why considerable investment has been made in the further development of this technology in recent years. Technological advances and economies of scale in production have brought down the price per installed kWp by around 14% per year in recent years [2]. Figure 2 shows that the reduction in PV module costs has made an enormous contribution here. The installation costs and the BoS hardware costs now account for 40% of the total costs, as the pie chart in Figure 3 shows. In the future, savings in this field will therefore have a much greater impact on the overall price.

This is where the aforementioned increase in output voltage comes into play. The currents can be reduced by increasing the system voltage. This leads to savings at various points: the most visible effect is the significant reduction of cable cross sections, as shown in Figure 4. This is because the required cable cross section increases approximately quadratically with the flowing current. In other words, doubling the output voltage (i.e. halving the current) leads to a reduction in the conductors' cross section of approximately 75%. Only the pure current-carrying capacity of a single conductor is considered here. If the cables are laid in bundles in the main lines of a power plant, the current-carrying capacity must be corrected downwards due to the poorer heat dissipation. This means that a larger cross section is required for bundled conductors in order to transmit the same current. By reducing the cross sections, the bundles also become smaller, which in turn means that smaller reduction factors can be applied for the bundling.

As a cable is not only made of copper, the monetary savings in bill-of-materials costs will not be the same due to the increased insulation. The increase in raw material requirements mentioned at

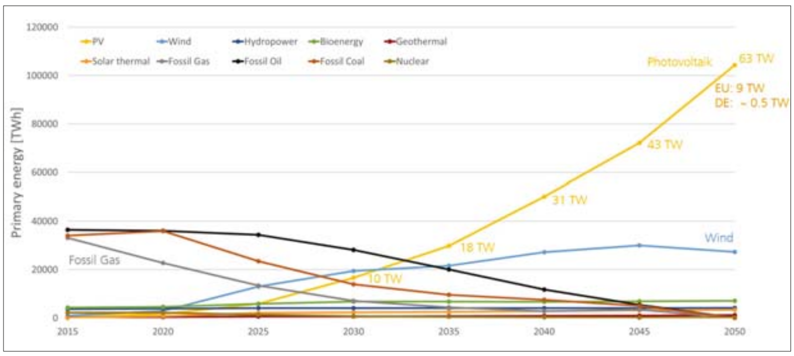


Figure 1. Development of primary energy distribution until 2050, diagram from Fraunhofer ISE, data [1]

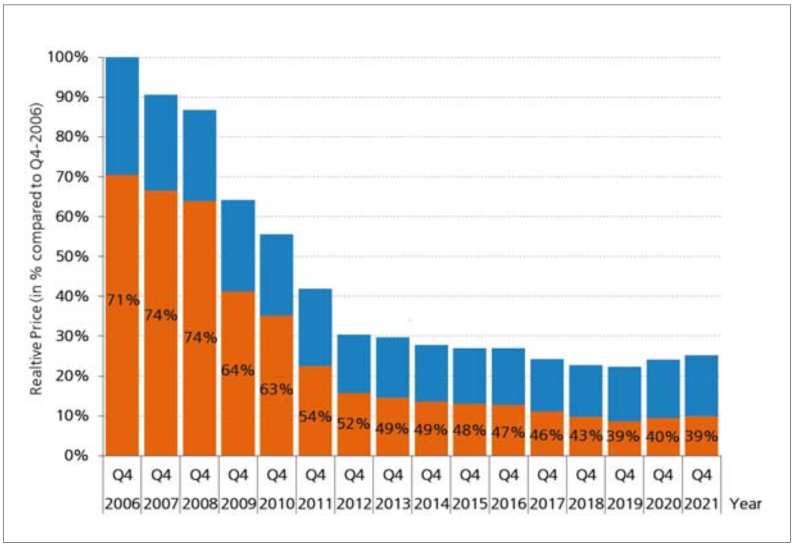


Figure 2. Relative development of the costs of PV modules and BOS components starting from 2006 [2]

the beginning and the associated price increases must be taken into consideration here. If the price of copper rises sharply in the future, the proportion of reducible costs in the overall cable will also increase [3]. In the case of cables, the savings potential lies not only in the pure material costs; the laying and connection of smaller cross sections is also much simpler, thus reducing installation costs.

But the move to medium voltage does not only affect the cables; the increased voltage can also increase the output of the subsystems. Today's power plants usually use subsystems between 3 and 5MVA in size. A higher output is difficult to achieve in a low-voltage transformer due to the large copper cross sections. If the voltage is increased, a winding with the same cross section can transmit a higher power. With a voltage of 1,500V, 10-12MVA is already possible in a transformer and thus in a substation. This results in a smaller number of transformers and switchgear, while the power plant size remains the same. This also means fewer construction works and lower installation costs. At the same time, there is more space for PV modules.

Obstacles

As Figure 5 shows, the above-mentioned potentials have been utilised in the past. As the power of the inverters increased, the output voltage also continued to rise. Since 2018, the increase in output voltages has stagnated despite further increases in output power.

The main reason for this development is the definition of "low voltage", which is limited to 1,500Vdc or 1,000Vac. Above this value, the "medium-voltage" range begins, which is internationally

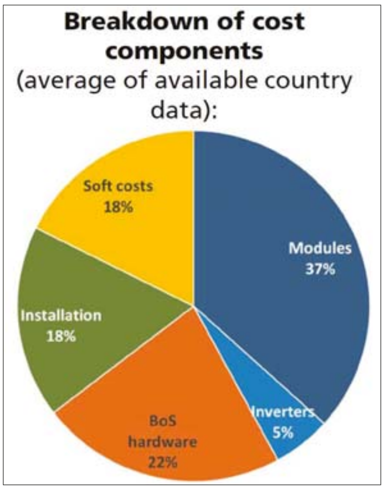


Figure 3. Breakdown of component costs according to their shares in a utility-scale power plant [2]

part of the high-voltage range. However, all PV-specific standards are currently only available for low voltage. A further increase is therefore associated with a significantly higher standardisation effort. This is because not only do the PV-specific standards themselves have to be adapted, but they also refer to other basic standards from the medium-voltage field of application.

At this point, a chicken-and-egg problem arises: without increased interest from the industry, the standardisation committees will not tackle this major standardisation issue. On the industry side, however, the lack of a normative basis and test specifications is an obstacle to the move to medium voltage.

However, the standardisation situation is not the only hindering factor here. For the construction of a medium-voltage PV power plant, a wide variety of new components from different manufacturers is needed. Here too, one manufacturer has to lead the way. But all beginnings are difficult because the introduction of a new technology lacks any economies of scale, which makes pricing more difficult. This is a particular hindrance in a price-sensitive market such as the PV sector. Added to this is a rapidly growing market with increasing demand. The resulting certainty in sales has reduced the pressure on component manufacturers to innovate.

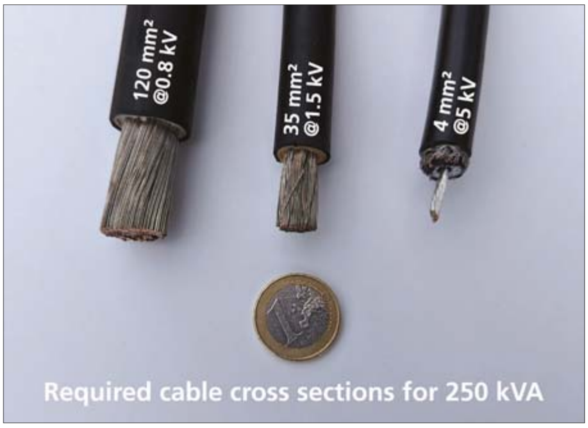
Another reason was the challenge of producing a highly efficient inverter for medium-voltage applications. For the step up to medium voltage, semiconductors with blocking voltages above 1.7kV are required. Silicon components have switching speeds that are too low for this application and therefore lead to increased losses. Highly efficient inverters for medium-voltage applications can only be built with silicon carbide (SiC) components with high blocking voltages.

State of the art in research and technology

In the early days of SiC semiconductor development, there was great euphoria around the technology, and the advantages of wide bandgap devices were demonstrated in a wide variety of components. These included components with blocking voltages of up to 25kV. Even back then, higher voltages were being considered in the field of PV and the first research projects were underway [5]. However, the costs of the new semiconductors were still too high and the technology was still plagued by various teething troubles. This meant that components with high blocking voltages in particular were still too far away from being ready for serial production. With the rise of electromobility and the increasing demand for <1.7kV SiC components, all manufacturers focused on optimising these voltage classes. The further development of components for higher voltage classes came to a standstill.

SiC has now fully arrived in electromo-

Figure 4. Minimum cable cross sections for 250kW at different AC voltages



Credit: Fraunhofer ISE

PV deployment: record growth in 2023

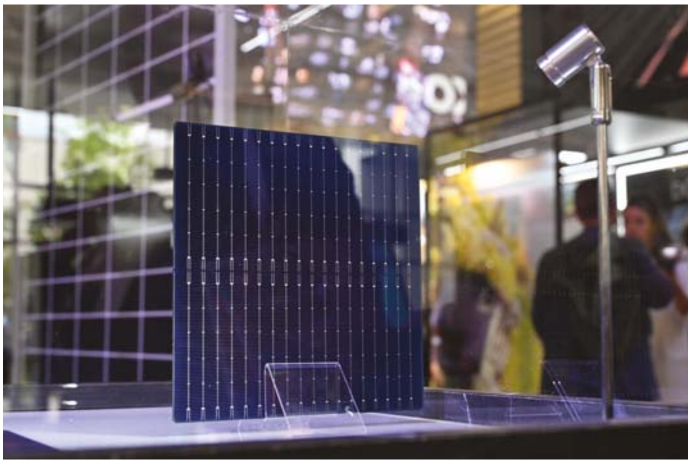
According to the latest market survey by the European solar association, Member States of the European Union (EU) have experienced another record year for PV deployment in 2023. For the third year in a row, the market grew by 40 percent or more, to around 56 gigawatts (GW). With 14 GW of new installations, frontrunner Germany was the first EU country to exceed the 10 GW mark. The Italian market doubled to 4.9 GW, while the Austrian market grew by a whopping 114 percent to 2.2 GW.

According to the market survey, 2023 was the best year for solar power in 20 of the 27 EU member states, with 14 countries installing 1 or more gigawatts. The combined installed capacity in the EU now amounts to 263 gigawatts. The driving force in Europe continues to be the rooftop segment – commercial and industrial (C&I) grew by 4 percent to 33 percent (compared to residential installations (33 percent), and large installations (34 percent)).

The largest markets 2023: Germany, Spain and Italy

Germany climbs back to the top of the EU rankings of 2023: The reform of the Renewable Energy Sources Act (EEG) in July 2023 has created improved market conditions with more surfaces available for construction and higher feed-in tariffs. The German market has doubled in size compared to 2022.

(Picture source: Solar Promotion GmbH)



(Picture source: Solar Promotion GmbH)

The solar nation of Spain took second place with 8.2 GW growth, which means it grew 0.2 GW less than in 2022 (8.4 GW). Italy saw record growth in 2023, placing it among the top five solar nations for the first time in a long time. One of the drivers is PV deployment in the C&I segment. Poland made fourth place with 4.6 GW, which was 0.1 percent more growth than in 2022 (4.5 GW). With 4.5 GW growth, the Netherlands ranked fifth – and were once again leading in terms of installations per capita (1.280 watts/capita). The next countries in the market growth ranking are France with 3.0 GW, Austria with 2.2 GW, Belgium with 1.7 GW, Greece with 1.6 GW and Hungary, also with 1.6 GW.

Come to Intersolar Europe 2024 to learn more about the most important market developments taking place in Europe! From June 19–21, you can check out the latest applications and technologies at Messe München: From PV power plants, hybrid power plants, combinations of PV, storage systems, heat pumps and electromobility to agrivoltaics and floating PV. Industry players and start-ups will showcase innovative cell designs and high-performance solar technology. Learn how renewables are revolutionizing our energy system and providing clean energy 24/7.

www.intersolar.de/home

(Picture source: Solar Promotion GmbH)

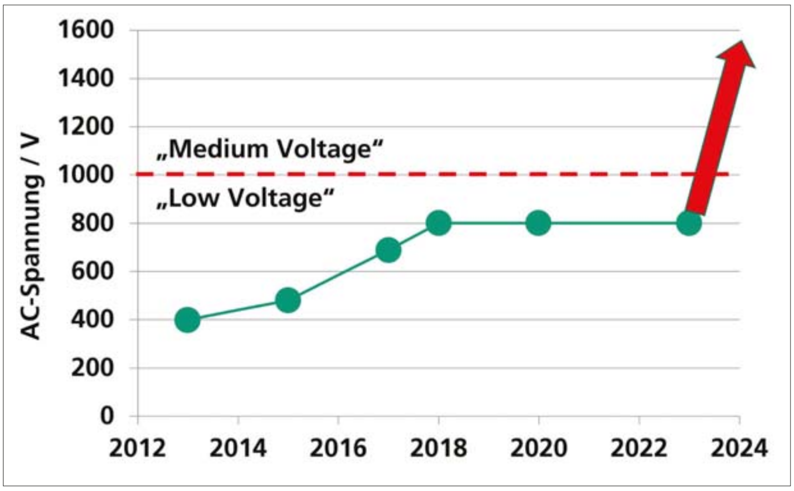


Figure 5. Development of the output voltage and power of string inverters in recent years [4]

bility. More manufacturers are once again focusing on the higher voltage classes. The 3.3kV class is available on the market from various manufacturers and the 6.5kV class is well on its way to serial production. In the meantime, various research projects have shown that the construction of highly efficient inverters based on SiC is technically feasible.

Researchers at Fraunhofer ISE have developed the world's first medium-voltage string inverter and successfully put it into operation on the grid (see main image) [6]. It was developed as part of the publicly funded MS-Leikra project. The inverter has an output voltage of 1,500Vac with an output of 250kVA. It has a two-stage design. The step-up converter with a PV input voltage of 1.7kV to 2.4kV is based on 3.3kV SiC semiconductors. The inverter section was constructed using hybrid ANPC modules. Four silicon and two SiC semiconductors are used here. This topology allows the major advantages of SiC to be utilised at only slightly higher costs.

Higher voltages are also possible. A three-phase converter with 3kVac/250kVA was also developed at Fraunhofer ISE (Figure 6) [7]. The converter unit can be connected in parallel on the DC and grid side, each with its own LCL filter. It is an ANPC topology with 3.3kV SiC MOSFETs, using three half-bridge modules per phase. The switching frequency at the transistor is 16kHz. The PWM-pattern of the ANPC generates a ripple frequency of 32kHz for the alternating part of the current. This helps to decrease the filter effort. Depending on the design of the inverter, up to 2MVA can be realised in a control cabinet with a floor space of 80x80cm.

The University of Texas has also developed a medium-voltage inverter based on SiC. The nominal voltage here is 4.16kV with an output of 1MVA. New power plant concepts were also devised in this project in order to increase efficiency at the overall system level [8].

The current situation and the market

The projects mentioned show that the technological course has been set for the transition to medium voltage. At the same time, the technical innovation potential for photovoltaics in the low-voltage range is heavily saturated. Technological advances and thus unique selling points are only possible to a very limited extent, making price the main selling point. This poses major challenges for European manufacturers in particular.

The market situation and the rising raw material prices in recent years have increased the pressure to innovate. In the meantime, there have been initial advances in the direction of higher voltages. One example is the Mengjiawan project in Yulin City in the Shanxi province of China. Here, a pilot plant with a DC voltage of 2,000V was built and put into operation [9].

The researchers at Fraunhofer ISE are now convinced that it is no longer a question of whether the technology will take hold, but who will be the first players on the market and thus determine the technology. As already shown above, the global demand for installed PV power will be 63TW in 2050. There is a huge market here. According to [10], the share of utility-scale power plants, and thus the area of application for medium voltage, is between 40% and 60%. This is a great opportunity for Western manufacturers to regain technological leadership, at least in the area of utility-scale power plants. If a powerful consortium can now be founded, in which all the important suppliers of a utility-scale PV power plant are covered, the remaining hurdles can be tackled together.

This approach has several advantages:

1. The joint approach reduces the risk of developing a product that does not make it onto the market due to a lack of other components.

2. If the power plant is viewed as a whole with all the required technologies and their strengths and weaknesses, the entire power plant can be optimised. In this way, higher yields can be achieved over the service life.

The issue of standardisation

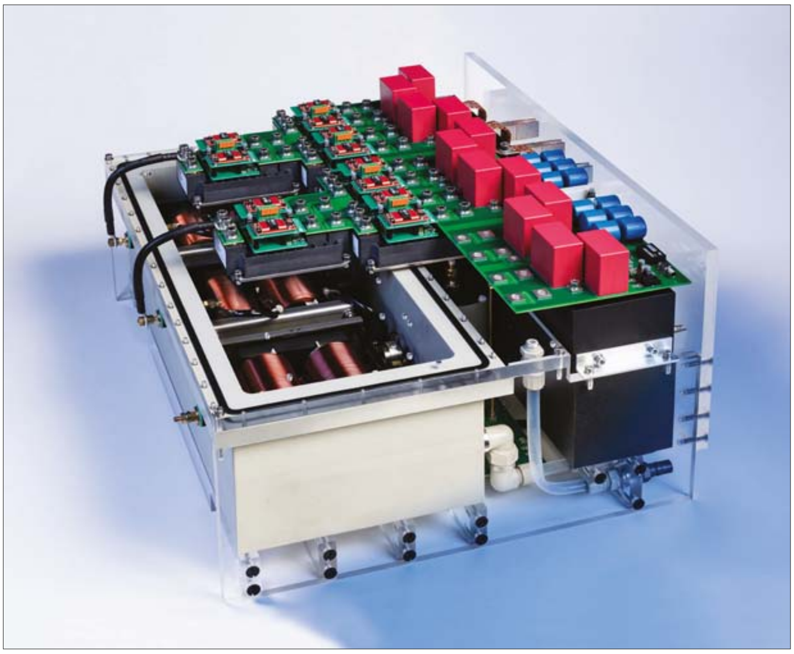
The problem of the lacking standardisation is now also being addressed. During the MS-LeiKra research project [6], a standards search was also carried out for the AC side. By drawing on standards from other areas such as electrical machines, all aspects would be covered. What is missing is the transfer of this knowledge into specific product and test standards.

The standardisation committees have now recognised the increased interest in the topic of medium voltage and are shedding light on the subject. As far as the DC side is concerned, a proposed standard for voltages up to 3kV is currently being developed at IEC level. This means a doubling of the maximum 1,500V possible today.

The first test specifications also exist in the field of testing. TÜV Rheinland, for example, has developed first internal test specifications (2PFGs) for PV modules up to 2kV and offers testing in accordance with these [11].

Whether an increase in voltage to 3kV is sufficient, or whether the economic optimum point is slightly higher, must be determined by further investigations. From the point of view of SiC semiconductors alone, higher voltages could also be implemented in the near future with 6.5kV components.

One frequently mentioned point of criticism of the move to medium voltage is the significantly increased safety requirements and the resulting need for additional training for employees. Those requirements are justified. If you look at the scope of applications of medium voltage, which is part of high voltage internationally, this extends to over 100kV. Historically, the main requirements come from the grid sector. In principle, however, the same physical laws apply directly



Credit: Fraunhofer ISE

Figure 6. A 250kVA inverter stack with 3.3kV SiC transistors developed at Fraunhofer ISE

below and above after the lower limit of 1,500Vdc . The introduction of a further voltage range of "low medium voltage" could be considered in terms of standards. The exact limits remain to be discussed but could be between 1.5kV and 10kV, for example. This would allow the necessary requirements to be reduced to an appropriate level. With photovoltaics as the only field of application, this would probably be a step too far. However, as considered in more detail in the next section, this lower range of medium voltage is also very interesting for other large fields of application in which similar savings potentials arise.

Applicability to other areas: PV, wind, storage, charging

In addition to utility-scale PV power plants, wind power plants, industrial grids in heavy industry and the charging of electric vehicles, ships and aeroplanes are interesting areas of application for low medium voltage.

In very large industrial plants with large dimensions and high demand for process heat, for example, local renewable energy generators could be connected to large heat pumps using an MVDC bus with lower losses and lower material costs.

In the field of mobility, the electrification of trucks, ships and planes continues to progress. Due to the large battery capacities, high charging capacities are required to enable fast charging. Here, too, simplifications could be achieved by increasing the voltage and thus lowering the current. Lighter cables and plug contacts make the system easier to use. In addition, the current heat losses in cables and plug contacts can be greatly reduced. Even when charging normal electric cars, medium voltage can bring significant potential savings – not directly in the vehicle, but in the underlying infrastructure.

Many new charging parks are needed to enable electromobility. In Germany, there must be a charging point for cars and trucks every 50km along the highways. To meet the necessary demand, the stations will have a grid connection capacity of up to 33MVA [12], which is equivalent to a small town. To relieve the load on the grids, it makes sense to use a combination of on-site renewable generation and storage. Through the roofing of the parking lot areas, there is very large PV potential on site. However, the connected load must also be distributed on site and routed to the individual charging points. To achieve a high level of efficiency and limit the use of materials, the move to medium voltage is also a very sensible approach here. As PV, storage and charging technology are DC-based, an MV-DC bus system would probably be the most efficient solution in the future.

The same approach is also conceivable in the area of hybrid power plants. Photovoltaic and wind power plants, batteries and electrolysers could be combined very efficiently with power plant-internal MV-DC bus systems.

As already described, the future costs of various individual components are important. The use of medium voltage in all of the areas mentioned will expand the market further. This means that more significant economies of scale can be achieved in terms of component costs. In addition, a broader field of application provides increased market security for developers of components for this field.

Summary

Contrary to all the hurdles in the past, the signs are currently looking good for the introduction of medium voltage in PV. The technical feasibility has been demonstrated several times. The first steps have already been taken by various manufacturers and the first pilot systems are already in operation. The problem has also been recognised on the standardisation side, and the committees are working on the important normative basis for this step towards resource-saving renewable energy generation. At the same time, there are other areas of application where risks can be minimised and costs reduced. What is now missing is a powerful consortium that can jointly remove the remaining hurdles and thus pave the way. ■

Authors

After training as a state-certified electrical engineering technician (2010 to 2012), Michael Geiss studied electrical engineering and information technology at Leipzig University from 2012 to 2017, specializing in energy technology. After completing his master's degree, he has been working at Fraunhofer ISE in the High Power Electronics and Systems Engineering group. His focus in various research projects is on medium-voltage applications. Since 2019, he has been project manager of the "MS-LeiKra" project, in which the world's first medium-voltage string inverter for photovoltaics was developed.

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How do you solve a problem like interconnection?

Grids | Grid bottlenecks have emerged as a significant obstacle standing in the way of the energy transition in the United States, with gigawatts of projects sitting in interconnection queues. Michele Boyd, Will Gorman, and Diane Baldwin report on work taking place at the federal level to address the interconnection challenge


The connection of solar, storage and other renewables to the US can be a lengthy process

Credit: Nexamp

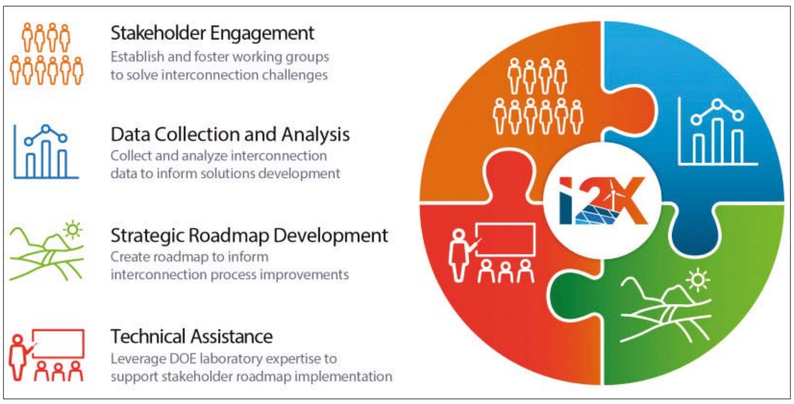
Decarbonising the US electricity system will require fast and efficient integration of clean energy generation while enhancing grid reliability and resilience. While the actual construction of clean energy projects might take as little as a few months, the institutional process to interconnect those resources to the grid can take years. Current interconnection procedures are not designed to accommodate the deployment of hundreds of gigawatts of solar, wind and energy storage resources needed each year to meet the Biden Administration's goal of a decarbonised electricity sector by 2035. Solving interconnection delays and streamlining processes requires an open, inclusive, and collaborative "all hands on deck" approach. In June 2022, the U.S. Department of Energy (DOE) launched the Interconnection Innovation e-Xchange (i2X) to convene stakeholders – grid operators, utilities, federal, state, and Tribal governments, clean energy developers, energy justice groups, researchers, and others – to identify interconnection barriers, share best practices and lessons learned, and test innovative solutions to specific interconnection challenges.

Where we are now

Grid interconnection, the process of connecting generators or energy storage to the electric transmission or distribution grids, has emerged as one of the most significant obstacles to the energy transition in the United States. For developers, long queues of projects requesting interconnection agreements and unknown or very high interconnection costs can result in lengthy delays and, potentially, in project cancellations. At the same time, the large number of interconnection applications for renewable projects has challenged grid operators tasked with maintaining the safety, reliability and security of the grid. The complexity of interconnection makes it what is referred to in system dynamics literature as a "wicked problem"—a multifaceted challenge that has many different causes, many stakeholders, and no single solution.

Generator interconnection procedures were designed for a grid powered by a smaller number of large, centralised generators, primarily interconnected to the transmission grid. The increased number of smaller, decentralised renewable systems with different technical characteristics being interconnected to both the transmission and distribution systems has strained existing procedures and introduced new grid challenges. While the Federal Energy Regulatory Commission (FERC) and transmission grid operators, as well as state regulators and distribution utilities, have adopted a range of reforms to interconnection policies, procedures, and tools, more work is required to keep pace with the changing technologies and generation mix needed for the energy transition.

The mission of DOE's i2X programme is to enable simpler, faster, and fairer interconnection for clean energy generation and energy storage, while enhancing the reliability, resilience and security of the



The i2X programme facilitates solutions to interconnection challenges by conducting four key activities

Source: The U.S. Department of Energy

grid. More than 530 organisations, representing the full range of interconnection stakeholders, have joined i2X as partners and thousands of people have actively engaged in i2X workshops. i2X is gathering baseline information to track progress and identify successful strategies, as well as providing technical assistance to support stakeholders in improving interconnection practices and processes. i2X is also developing two roadmaps, one focused on the transmission grid and the other on the distribution system grid, to systematically identify solutions to improve interconnection processes.

The interconnection process

Interconnection processes vary significantly, depending on the geographic location of the proposed generator or energy storage asset and whether it is accessing a lower-voltage distribution system, higher-voltage transmission system (bulk power system), or the in-between (sub-transmission). Notionally, however, these processes have similar steps. A customer—the entity that wants to interconnect a new generator or energy storage asset, usually a private developer—submits an interconnection request to the relevant grid operator. Depending on the point of interconnection, the grid operator—either a transmission provider or a distribution utility—places the interconnection customer's request into its interconnection queue.

Through a series of technical screens or detailed interconnection studies, the grid operator will evaluate how the proposed generator would affect its grid system's safety, stability, power quality and reliability. For most small-scale generators below a certain capacity threshold (e.g., 50 kW) in distribution systems, the studies are fast-tracked through technical screens to grant interconnection agreements. In some cases, upgrades to the grid system might be needed to connect the generator safely and reliably. As proposed generators advance through the interconnection queue with detailed studies, they may have additional requirements.

At this stage, customers will also obtain more accurate information from the grid operator about the interconnection costs associated with the project. Interconnection costs can include local facilities costs and broader network upgrade costs to ensure a safe and reliable grid system. Interconnection customers typically must pay upfront for all or some portions of the facilities and network upgrade costs. An interconnection customer can withdraw its request from the queue at any point, which may affect the remaining interconnection requests, triggering a restudy or changing interconnection costs for others in the queue.

Once an interconnection customer completes all the steps and requirements of the interconnection evaluation process, the customer will sign an interconnection agreement. After the agreement has been signed, network upgrades have been made and the generator has undergone inspection and testing, the new facility is then ready to be energised and begin delivering power to the grid.

FERC, which is responsible for regulating the interconnection process for the interstate bulk power system, recently issued the first major change to its interconnection procedures in nearly two decades. This update, FERC Order 2023, is an important step to standardising interconnections across the country and speeding the process of clearing transmission interconnection queues. FERC Order 2023 makes several significant reforms to current procedures, the central of which is to implement a "first ready, first-served" cluster study process. This reform requires that transmission providers study potential new generation in groups by location and time of entry to the queue, rather than reviewing projects one by one. The order also requires customers to pay higher deposits, demonstrate site control and pay withdrawal fees; fines grid operators and utilities that do not adhere to the interconnection studies timelines; and allows co-located resources, such as solar-plus-storage projects, at a single point of interconnection, to submit one interconnection request rather than requiring separate queue entries.

Rising transmission interconnection costs and delays

The total capacity in transmission interconnection queues is growing annually. As of the end of 2022, more than 1,350GW of generation and an estimated 680GW of energy storage were active in the queues (Figure 1), exceeding the installed capacity of the entire US power plant fleet (~1,250GW) [1]. Requests to connect new solar capacity (947GW) and new wind capacity (300MW) approaches what is needed to decarbonise the grid by 2035 [2]. A significant portion of this proposed capacity, however, will likely not be built: only 14% of the generator capacity requesting interconnection from 2000 to 2017 has been built as of the end of 2022 [1].

As the transmission interconnection queues have grown, so have queue wait times. The median time from the submission of an interconnection request to an interconnection agreement has increased sharply since 2015, reaching 35 months in 2022 (Figure 2) [3].

Costs have also grown over time in five wholesale US electricity markets, though they vary considerably by location (Figure 3). Most of the cost increases were due to network upgrades that were determined to be necessary to connect new generation safely and reliably. In some cases, the costs of interconnecting to the grid can become high enough to jeopardise the economic feasibility of a project, which can influence a developer's decision to withdraw from the queue. Projects that withdrew had much higher interconnection costs than active or completed projects. In PJM's queue, for example, projects in the queue in 2022 had mean interconnection costs of US$240/kW of capacity, while projects that withdrew between 2020 and 2022 would have cost US$599/kW [4]. When potential

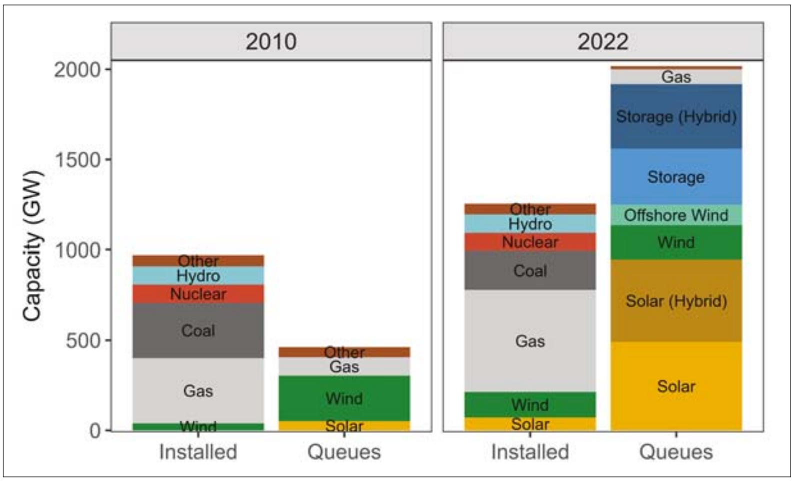
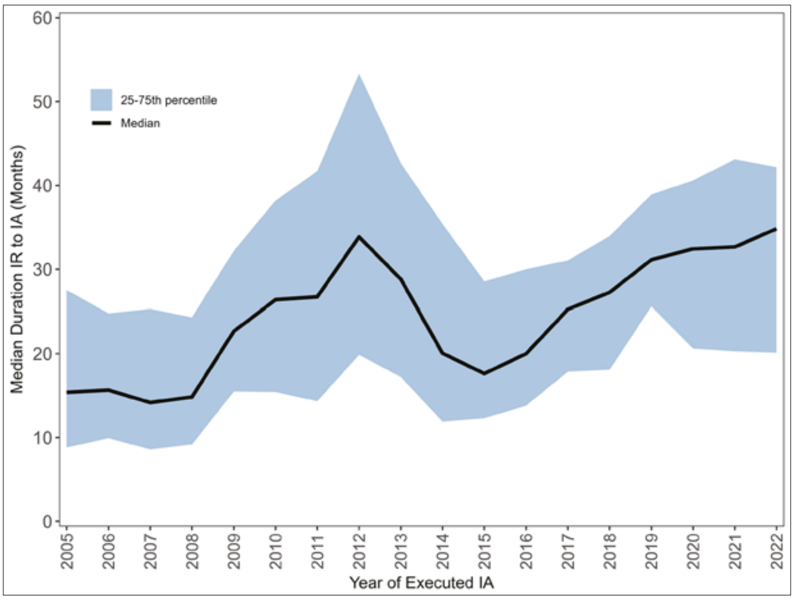


Figure 1. The entire US installed generating capacity compared to active transmission interconnection queue capacity

Source: Lawrence Berkeley National Laboratory



Source: Lawrence Berkeley National Laboratory

Figure 2. Median duration from interconnection request to interconnection agreement, based on 3,348 projects from six ISO/RTOs and five non-ISO utilities with executed interconnection agreements since 2005

energy generators withdraw from the interconnection queue, those network upgrade costs may then be imposed on other developers—which can lead to a cascade of withdrawals of potential renewable energy projects.

With almost 3,000 distribution utilities that manage interconnection to distribution system grids in the US [5], data on distribution interconnection timelines and costs are more dispersed than for the transmission grid, and in most cases are not collected or released publicly. A few states require the collection and publication of this data (e.g., CA, HI, NY, MA), but most do not. DOE is exploring options to collect data on the interconnection timelines and costs of distribution grids.

Where we need to go

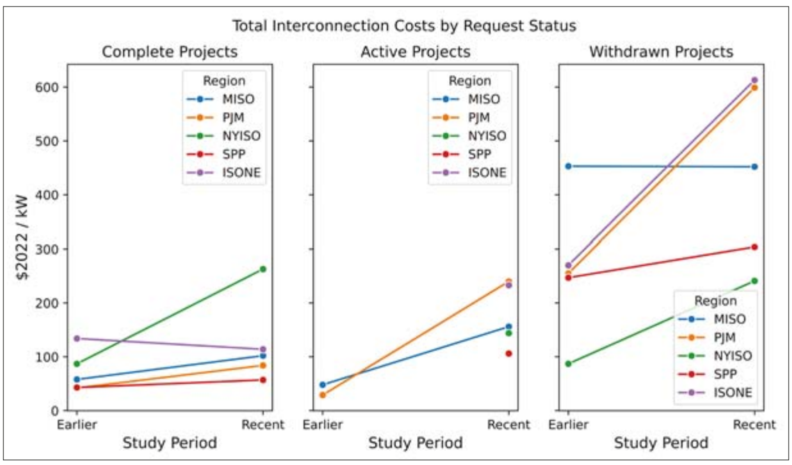
Transmission roadmap

In October 2023, after extensive stakeholder input, DOE released a draft transmission interconnection roadmap, which is intended to serve as a guide to key actions that stakeholders should take in the next five years and beyond to implement solutions to interconnection challenges and to clear the existing backlog of solar, wind and energy storage projects in the queue. It also establishes high-level, measurable targets for 2030 to provide a vision for interconnection reforms and gauge progress.

Interconnection reform is a group effort. Thus, the solutions in this roadmap describe actions for a range of different actors. For each solution in this roadmap, specific stakeholder groups are identified and assigned suggested actions. DOE has multiple roles: convening stakeholders, facilitating solution adoption, providing technical assistance, supporting the research community and potentially becoming a solution provider.

The draft roadmap is organised into four primary goals and identifies more than 30 solutions that are intended to be a collection of viable strategies rather than a rigid package of prescriptive fixes (sampling in Table 1). While the roadmap solutions align with current regulations, it introduces additional ideas to support implementation and interconnection process evolution. Each solution has a timeframe that indicates how long the solution might take to implement: short-term (1-3 years); medium-term (3-5 years); and long-term (>5 years).

1. **Increase data access and transparency:** Improvements to interconnection data transparency, beyond those in FERC rules, would help to improve interconnection customers' ability to site potential projects and better enable third-party modeling and more process automation, as well as benchmarking, tracking and auditing of interconnection processes and reforms. Notably, this includes increasing transparency around timelines, costs and delays in the period after an interconnection agreement is signed. Increasing transparency should generally increase fairness, equity and competition in the interconnection process while lowering the number of non-viable, ultimately withdrawn projects and increasing the proportion of high-quality, well-sited projects in the queue.
2. **Improve process and timing:** Interconnection backlogs and delays are often the result of rapid growth in interconnection queues, inefficiencies in interconnection processes, and staffing constraints. Interconnection queue volumes in the US are likely to be large and potentially volatile for the foreseeable future. Streamlining interconnection processes and improving the viability of projects applying for interconnection as the total volume remains high should help mitigate existing queue backlogs and decrease the time required to interconnect, all while maintaining open access principles that remain central to resource development. Solutions address improving queue management practices, affected system studies, inclusive and fair processes, and workforce development.
3. **Promote economic efficiency:** Interconnection and transmission planning are closely related. Proposed generators not selected through long-term transmission planning may trigger the need for broader network upgrades to interconnect. How to allocate these costs has proven to be one of the most difficult interconnection challenges, requiring decision makers to carefully vet and weigh diverse stakeholder perspec-



Source: Lawrence Berkeley National Laboratory

Figure 3. Interconnection costs (US$/kW) by request status over time in five wholesale U.S. electricity markets (MISO, PJM, SPP, NYISO, and ISO-NE)

tives according to specific objectives. Solutions aim to improve cost allocation, enhance the coordination between transmission planning and the interconnection process and right-size transmission investment through improvements in interconnection studies that help reduce costs to consumers.

4. **Maintain a reliable and resilient grid:** Historically, the goal for connecting wind and solar with inverters was primarily to deliver power to the grid and they were therefore disconnected during grid disturbances. Given the growing number of inverter-based resources on the grid, these generation sources increasingly need to ride-through disturbances and support grid recovery. Requirements for ride-through, however, are not always defined and do not include performance specifications during other accompanying events on the grid. Solutions aim to reduce these gaps by updating technical requirements within interconnection studies, models and tools, while also improving industry interconnection standards.

Equity is not a standalone goal in the roadmap, because it is integral to each of the goals. Energy equity in interconnection requires intentionally designing systems, technologies, procedures and policies for all types of interconnection stakeholders, particularly disadvantaged and energy justice communities who may lack the financing, resources and capacity needed to navigate interconnection. Solutions in multiple sections specifically aim to resolve current issues of equity within the interconnection process.

The final roadmap will be published in early 2024.

Preview of distribution system roadmap

While technical requirements for transmission interconnection are mandated by FERC, interconnection on the distribution and sub-transmission systems is a patchwork of regulations, processes, timelines and costs. State-regulated electric utilities are under the jurisdiction of individual state public utility commissions (PUCs). A significant portion of the nation's untapped renewable energy resources, however, are in rural areas that are served by more than 800 consumer-owned utilities, which have their various regulatory environments [6].

Distributed generation and energy storage have continued to skyrocket in growth, with the DOE estimating that the total capacity of distributed energy resources (DERs) in the United States will grow to 380GW in 2025, more than a 300% increase from the 90GW in operation in 2022 [7]. Energy storage and electric vehicle-charging infrastructure pose particularly unique challenges to the interconnection study processes used by many utilities. Interconnection processes and standards will need to evolve to handle the increasing number of requests, as well as increasing complexity of DERs, as policy and economic drivers continue to motivate significant resource development.

In response to this continued expansion, FERC adopted Order 2222 in 2020, which allows aggregations of DERs to participate directly in wholesale electricity markets [8]. The order allows DERs to sell excess electricity to the bulk power grid, like transmission-interconnected generators already do, and requires ISO/RTOs to remove barriers to participation in these markets. Navigating this and other changes will require unprecedented coordination between transmission and distribution system operators at all levels, including system planning, standards adoption, market design, and regulation.

DOE is currently developing a DER interconnection roadmap that will identify key actions that stakeholders should take to implement solutions to interconnection challenges on the distribution and sub-transmission systems. Like the transmission roadmap, a draft will be released for public comment before it is finalised.

A few of the solutions that will be outlined in the draft distribution system roadmap include:

- **Establish and maintain hosting capacity analysis (HCA) tools:** Some distribution utilities have begun to develop maps that provide developers with information on where interconnection costs may be lower due to sufficient feeder headroom (hosting capacity), and where interconnection may trigger expensive upgrades due to capacity constrained feeders. While these maps can enable developers to make more informed decisions during project planning and reduce exploratory interconnection requests, issues of accuracy, granularity and timeliness of the data, as well as the cost and lack of automated processes to develop and maintain them, need to be addressed.
- **Enable flexible interconnection:** Historically, utilities have used physical infrastructure to expand grid capacity for interconnection by sizing capacity to the maximum generator output plus a buffer margin, often leading to costly system upgrades that address grid violations only occurring a few hours out of the year. Flexible interconnection is a strategy in which generator output is controlled and monitored in real time by the utility, and production is curtailed within an agreed set of parameters when there is a threat to system reliability or power quality. Flexible interconnection can remove the need for costly system upgrades and allow for greater grid utilisation and faster and cheaper interconnection, while having minimal impact on the economic viability of a project. While

Table 1. Sample solutions from the i2X Draft Transmission Roadmap

Goal 1: Increase Data Access and Transparency	Goal 2: Improve Process and Timing	Goal 3: Promote Economic Efficiency	Goal 4: Maintain a Reliable Grid
Improve the scope/quality of data on projects already in interconnection queues (short-term)	Assess scale of interconnection workforce growth requirements (short-term)	Ensure that generators have option to be re-dispatched rather than pay for network upgrades (medium-term)	Adopt comprehensive set of generation interconnection requirements consistent with IEEE Standard 2800-2022 (short-term)
Enhance the accuracy, timeliness and availability of interconnection study models and modeling assumptions (medium-term)	Increase voluntary collaboration on affected system studies (short-term)	More closely align interconnection and transmission planning processes (medium-term)	Require submission of verified Electromagnetic Transient (EMT) models for all inverter-based resources; develop screening criteria to determine when EMT studies are necessary (short-term)
Develop tools to visualise transmission and interconnection data (medium-term)	Consider market-based approaches to rationing interconnection access (long-term)	Continue to develop new best practice study methods, and harmonise methods to adapt to a changing generation mix (medium-term)	Evaluate cybersecurity concerns during the interconnection process (medium-term)

Source: U.S. Department of Energy

some utilities in Europe and Australia already use flexible interconnection, the approach is in its infancy in the United States [9] and standards and guidelines still need to be developed.

- **Enable alternatives for direct transfer trip (DTT):** DTT is a system protection and safety feature commonly used on distribution grids to mitigate islanding and overvoltage risks from DERs. The cost and complexity of implementing DTT, however, is a significant hurdle for many DER projects and a common reason for withdrawal from the interconnection queue. Solutions include developing guidelines for alternatives to DTT and researching methods to evaluate the effectiveness of DTT deployment relative to the cost.

Interconnection challenges on the distribution grid can be particularly evident for energy justice communities, Tribes, and other disadvantaged communities that are interested in accessing the benefits of clean energy. For example, interconnection cost uncertainties or delays can derail community solar projects that make solar more accessible to all Americans, particularly to those with low-to-moderate incomes and renters. Like the transmission interconnection roadmap, solutions to address equitable interconnection on the distribution system grid will be discussed throughout the document.

Conclusion

Although interconnection is a complex "wicked problem" without a single solution, the good news is that there is a collection of viable solutions that can address the technical, market, and administrative challenges of transmission and distribution system grid interconnection. Increased and sustained collaboration among all stakeholders, as well as implementation of innovative approaches and tools, can lead to an efficient, equitable, and modern interconnection process that ensures a clean, reliable, and secure electric grid. ■

Acknowledgments

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Four strategies to unlock millions in untapped value through solar module procurement

Modules | The dollar-per-watt metric has traditionally formed the basis of PV module purchasing. But as Anza CEO Mike Hall argues, this simplistic formula can lead to costly mistakes and stand in the way of getting the best value from procurement decisions

Credit: First Solar

Over the last five years, we've seen a massive transformation in how large-scale solar projects work in the US. When I started in the solar industry over 20 years ago, module and other major material procurement was primarily performed by EPCs and installers. Today, utility-scale and distributed generation owners have almost entirely taken on these responsibilities.

Coinciding with this transformation is an increasingly dynamic market. Module procurement teams must now navigate US Customs detainment (from UFLPA policy), AD/CVD duties, technology changes, price instability and a massive increase in viable module vendors. In the middle are procurement teams stuck managing these complexities with insufficient data, tools and frameworks for risk reduction, leaving them with limited time to manage other problems with ultra-long lead time components such as switchgear, transformers and specialty breakers. Multi-million-dollar decisions shouldn't rely on outdated, manual time-consuming processes that saddle resource-constrained procurement teams and lead to suboptimal results.

Throughout this article, we'll share what we see as some frequently overlooked but winning procurement strategies. In many cases, these recommendations conflict with the industry norms and past practices. At Anza, we're simply following the data.

Dollar-per-watt thinking reduces project returns

I started my career in solar in 2002, and for the last 22 years (and possibly longer), the industry has used the dollar-per-watt (US$/W) cost of modules to negotiate prices, build financial models and make procurement decisions. At first glance, it makes sense. There are several modules on the market, all with varying nameplate wattage. Power and energy are incredibly important when getting a project off the ground, so this is a simple way to rapidly compare products. The problem is in the vast majority of cases using the US$/W cost of modules will lead you to buy the sub-optimal module for your project.

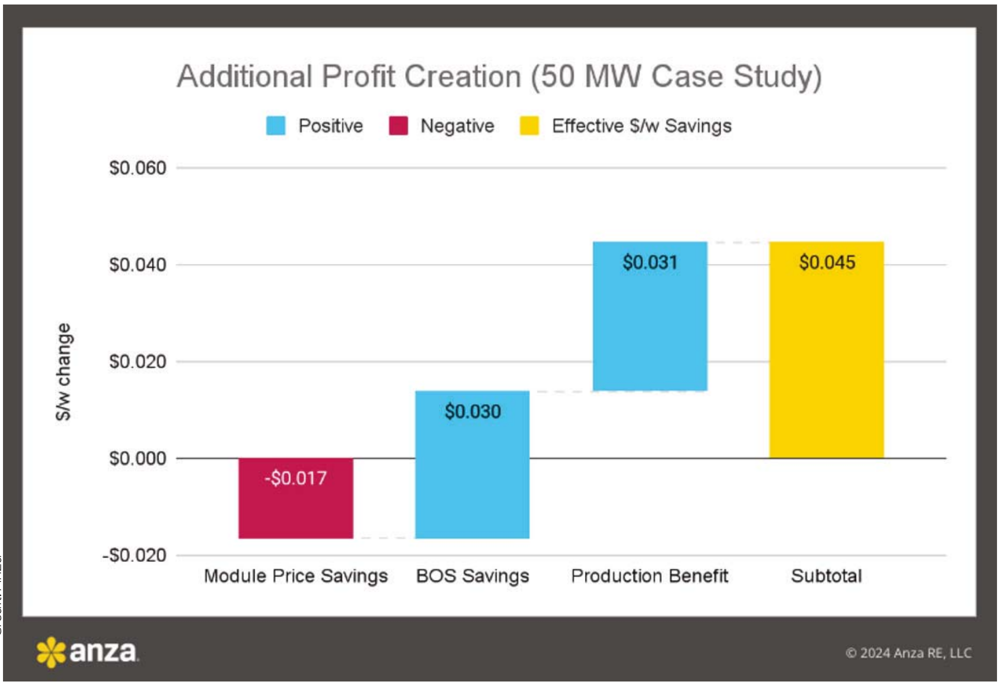
The lowest dollar-per-watt modules do not always represent the best value

Taking the module unit cost and dividing by nameplate watts (the US$/W strategy) ignores two critical components of financial value: energy production and installation costs. Every solar module has different performance characteristics, and while these differences are largest between technology families (between Mono PERC and TopCon cells, for example), they also exist between products of the same technology. Module-expected degradation, thermal performance, and non-incident light absorption are all factors that play a role. These variables are usually determined through third-party testing and represented in a PAN file.

Similarly, modules can also have materially different costs to install. Many factors can drive these differences; for example, generally (but not always) higher watt class modules – large format modules – are less expensive per watt to install because fewer pieces are required. Another factor, such as how the modules string or sit on the tracker, can also impact the balance of system (BOS) costs. So why does this matter? We often see examples of utility-scale solar buyers missing out on millions (or even tens of millions) of dollars in value by using $/W as the primary value metric.

For example, we worked with a client who was in the market for 50MW of modules for a single project. They had been focused on a low-cost Tier 1 Mono PERC product. However, we were able to show them that by paying 1.7 cents per watt more, they could get a more efficient module that generated additional energy worth 3.1 cents per watt and expected BOS savings of another 3 cents per watt. In aggregate, paying 1.7 cents more generated 4.5 cents in value. To put this in perspective, on 50MW, that's US$2.2 million— enough value to fund most procurement departments for several years. We've also seen utility-scale examples where buyers were likely to miss out on as much as US$30 million of value by ignoring these factors.

We saw that the market was missing critical data and analytics to perform these calculations. This is why we created the 'Effective $/W' metric. This metric incorporates the installation cost, balance of system impact and production revenue-related impacts into the module comparison. It is calculated by subtracting BOS savings and production benefit from module price. This analysis is something that has historically been completed manually, if comprehensively analysed at all, taking procurement teams weeks or months to compare prices and wasting valuable time and resources due to static pricing models and insufficient data.



Credit: Anza

Figure 1. A little more spent upfront on modules can generate millions of dollars of additional value over a project's lifetime

Bulk equipment buying can kill your bottom line

In working with utility-scale developers and independent power producers (IPPs) we've seen a recurring pattern. Large-scale buyers will package multiple projects (or even multiple years of demand) to get to increase order size. These often result in single orders over 500MW and, on occasion, even multiple gigawatts. The rationale is that economies of scale will drive down prices, generating significant savings. This makes sense in theory, but the problem is the data shows this just doesn't work in an industry that's constantly evolving.

A majority of large purchases result in non-optimal outcomes for several reasons. The first has to do with timing. When procurement teams are buying for multiple projects many quarters ahead of time, they have to make educated guesses about when modules will be needed on site. As anyone who has developed projects knows, construction start dates are incredibly difficult to predict a few quarters out (never mind six or more). Interconnection, permitting, M&A activity, and financing issues frequently delay projects. The larger the buy, the more guesses procurement teams have to make and the greater the cost associated with their inevitable misses.

Early module orders and shipments can kill your bottom line. They can tie up capital via early deposits and payments and rapidly pile up storage costs. Following a "just in time inventory" (JIT) strategy has proven to be a winning business strategy [1] — Toyota proved this during the pandemic when companies implementing a "just in case" inventory model ultimately fared worse. Big bulk buys are the enemy of JIT.

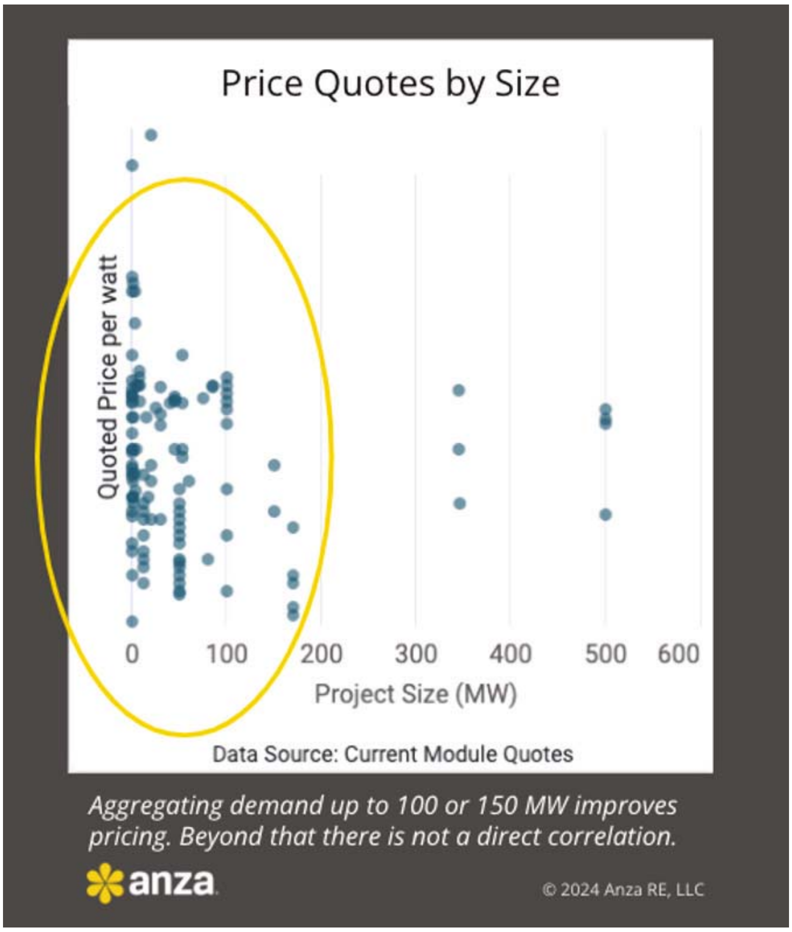
For example, one of our clients made a 100MW purchase to cover module supply for two projects. The purchase timing ended up being about two years too early. Just the warehousing costs alone for these modules ended up costing them US$3.75 million. Then, the question still remains whether these are the optimal modules for their project, as the cell technology and module costs have changed significantly in this period. Besides this example, we've arranged warehousing storage that has cost other customers of ours US$1.8 million in 2023.

The second issue is that once you pass around 150MW, there is no clear correlation between order size and price. At Anza, we work with over 70 large-scale developers and IPPs. At any given time, we're helping subscribers on multiple utility-scale procurements. We have more data on real price quotes than anyone else in the industry. Figure 2 shows a chart of our recent price quote data. You'll see that smaller distributed generation scale buyers pay a higher price than large utility-scale buyers. However, once you cross the 100MW line the correlation is weak. At that volume, other factors have a greater impact on the price than scale.

The final reason it doesn't make sense to do multi-project bulk buys is that the optimal module for one project may not be the best for all your projects. As mentioned above, price is only part of the financial equation when choosing a module. Energy production and BOS costs can be just as – or more – important. The problem is these factors are project specific. For example, if Project A has a PPA that's 10% higher than Project B, additional production is worth 10% more. Differences in weather can also drive changes in Effective $/Watt. At the utility scale, it makes sense to buy the best module for every project, and for that reason, we strongly recommend that utility-scale IPPs and developers procure one project at a time.

Savvy contract negotiation is crucial

I've been part of more M&A (both successful and unsuccessful) processes and worked with more investment bankers than I'd like to admit. One of the most glaring differences between the successful and unsuccessful processes I've participated in is how much



Credit: Anza

Figure 2. Larger projects do not always guarantee lower prices

of the term negotiation takes place before exclusivity. Eight-figure solar module purchases are no different. We often see large awards being made with only the most basic terms having been decided. Buyers and sellers will move forward with a simple price, product and delivery schedule agreement. Sometimes, even critical items like payment terms are left for later.

At Anza, we have consistently found that doing this wastes time, costs more and reduces the buyers' leverage in the negotiation process. There are critical risks and financial terms embedded in supply contracts that can be negotiated before issuing an award. These include issues around warranty, supply chain risk (e.g. UFLPA, AD/CVD, etc.), liquidated damages, QA/QC standards and serial defect clauses. Taking these terms as a whole could be financially impactful, often representing more value than the delta between short-listed bidders.

The challenge for buyers is often limited bandwidth and access to data. With forty Tier 1 module makers and an incredibly dynamic market, it's very difficult to know what the market terms are today. Furthermore, negotiating contracts pre-award with ten or more suppliers is impractical for most procurement teams. Even with those challenges it can be done, but structure and data are the key.

That's why it is helpful for buyers to have a solution like what Anza provides. We have executable supply contracts with over 30 suppliers representing approximately 95% of the US module supply. We've taken the key terms from those contracts and put them into a structured database that developers and IPPs can use to compare, contrast and filter vendors. This enables our subscribers to focus each vendor on what they need to do contractually to compete and win before an award.

Spend more time planning and less time doing

Another Toyota business practice that was introduced to me a decade ago is the Lean Management Foundation [2] (also from the Toyota Production System), and it has changed everything about how I look at business, operations and management. One of the most useful tools in Lean is the Plan Do Check Act (PDCA) cycle for continuous improvement. PDCA is a process based on the scientific method, arguing that if you spend more time upfront understanding the problem you are trying to solve, you'll get to a better solution faster than blindly moving forward. The same concept applies to solar module procurement.

Our experience has taught us that spending extra time to understand all of a project's requirements, showstoppers and preferences upfront can lead to faster and better execution. At Anza, we have a 75-point discovery process that we take every client through. To complete it, we need input from many different parts of an organisation, including procurement, engineering, development, legal and finance. When going through this process, we often find that procurement teams are given incomplete information from other parts of the organisation, which can impact decision making. It's hard work, but we recommend fleshing every detail out before going to the market for bids. Not doing so leads to lots of rework and wasted time for buyers and sellers.

As the industry moves at hyperspeed to get new solar projects online, there continue to be countless hours lost, project setbacks, and subpar product choices due to inefficient approaches to module procurement. While module prices have come down, they still comprise a significant share of the overall project cost and are a massive source of risk. If the modules don't produce as expected or the vendor doesn't deliver high-quality products on time, the project will suffer. Even more significant is the millions in untapped value that are forfeited, along with increased long-term capital requirements that ultimately dent profitability.

Our experience and data have shown us that many of the industries' past procurement practices aren't working. Large-scale developers and IPPs are unnecessarily tying up their balance sheets and missing out on better deals. We have seen that there is a better way. Broad adoption of renewable energy hinges on developers, IPPs and EPCs being able to make optimal project procurement decisions. It requires data, technology, process and collaboration. ■

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Authors

Mike Hall serves as Anza's CEO. He began his renewable energy career in 2002 when he co-founded Borrego with his brother, Aaron, and Chris Anderson. In 2021, Mike co-founded Anza in order to help IPPs and developers save time and increase profits by improving access to supply chain data and analytics. Today, Mike's focus is building Anza's platform to help the entire industry achieve superior project outcomes. He holds an M.S. in chemical engineering from Stanford University and a B.S. in chemical engineering from the University of California Santa Barbara.

Floating solar offers many advantages but also unique risks that insurers and asset owners should fully comprehend

Credit: Sungrow

Surveying the risk landscape of an emerging solar sector

Floating PV | As a fast-growing segment of the industry, floating solar is also a novel technology that comes with a variety of new operational risks. Bobby McFadden, kWh Analytics, Chris Bartle of Ciel & Terre and James Markos of Willis Towers Watson explore some of these and their implications from an insurance perspective

Solar power is expanding rapidly, accelerated by incentives like the US Inflation Reduction Act. With land constraints near populated areas, clean energy growth is occurring in floating photovoltaics on bodies of water, also called FPV or *floatovoltaics*. This novel technology functions much the same way as traditional solar, but instead of installing racking in or on the ground, panels are set atop floating platforms, with tethers from the platform to the bottom and/or shoreline of lakes, reservoirs, or quarries.

Though FPV today only makes up around 2% of new global solar installations [1], the fleet is growing and projects coming online rapidly. While this emerging technology presents exciting opportunities, it also brings new, previously unconsidered risks that insurers need to understand.

Floatovoltaics could be an ingenious way to generate necessary clean energy while saving precious land space. Some advantages of FPV include:

- **Makes use of unused space:** These projects are installed on non-recreational reservoirs, quarries, and ponds, utilising areas that would otherwise be unused.
- **Increased solar panel efficiency:** Positioning panels on water enables natural cooling that increases efficiency and output, especially during summer peak demand.
- **Grid connection benefits:** Co-locating projects with hydroelectric dams simplifies grid connections to export the solar power generated.
- **Repurposing contaminated waters:** Contaminated quarries and mining ponds can be repurposed for clean energy production.
- **Water conservation:** Covering water surfaces with floatovoltaics reduces algae growth and evaporative water losses.

However, floating solar has its challenges. The remote positioning of floating solar arrays in the middle of a water body can impact how a battery energy storage system might be utilised for additional revenue, depending on whether a DC or AC connection from the FPV is chosen. Current systems also do not employ trackers, whereby panels are tilted to the optimal production angle throughout the day. The nature of these systems requires specialised handling, equipment and maintenance, which can be time-consuming and costly.

Floatovoltaics, as an emerging technology, presents unique risks and opportunities that insurers, asset owners, and their brokers should fully comprehend. The unique benefits of repurposing non-recreational bodies of water also provide motivation. Beyond land constraints driving adoption, floating solar maximises the usage of available surface area to expand renewable energy generation potential compared to acreage-limited ground-mount developments. As further innovation addresses initial challenges, insurers can expect floatovoltaics' share of new solar installations to grow.

Technology overview & project development considerations

Fundamentally, floating solar installations utilise similar photovoltaic panels, inverters and other components as conventional ground or roof-mount solar installations. The differentiation arises in supporting these electrical assets over bodies of water instead of terrestrial real estate. This approach enables harnessing more surface area for solar resources without land constraints or clearing habitats. However, effectively designing equipment and infrastructure to withstand an aqueous environment also introduces unique engineering challenges.

Floatovoltaic systems comprise three primary elements – the floating platform, the electrical system and anchoring/moorings. A common floating structure typically uses modular HDPE or composite plastic floats connected via polypropylene pins to assemble into a unified array. Other float systems can include rafts, pontoons, or membranes. Strings of PV panels along with wiring, converters and combiner boxes mount atop this buoyant platform, elevated safely above water. Underwater or floating direct current (DC) cables then transmit generated electricity to shoreside inverters and switchgear equipment, typically located near existing transmission infrastructure, or can be fastened to a floating equipment barge. If inverters are on floats near the arrays, an AC cable would then connect to the shore tie. The extensive anchoring and moorings keep this floating island securely fastened through waves, winds and water level fluctuations. The system utilises spreader bars (where the mooring line assemblies attach to the floating asset site, or 'island') adjustable chains, galvanised steel cabling and elastic rope shock absorbers, all corrosive-resistant and expertly tensioned. Site selection and system design confront additional considerations compared to traditional solar developments. Typically, water bodies are chosen based on technical limitations and functionality. Sites with limited recreational use, such as hydro dams, quarries and reservoirs, make ideal placements for FPV. The water body itself must meet the following technical limits:

1. Max wave height: 1 metre
2. Max surface flow rate: 1 m/s
3. Lowest temperature: -40 F/C
4. Max ground snow load: 60 pounds per square foot
5. Max water level variation achieved to date: 100 feet

Choice waterbodies limit sediment accumulation and depth changes while avoiding valuable recreational or commercial navigation routes. The bottom of the waterbody must be reachable in case maintenance activities or cleaning is required. The choice of site is extremely important: islands can be moved around on the water surface but are not intended to be removed or disassembled until decommissioning. If moving them, there needs to be secondary sets of anchors installed so the island(s) are always anchored.

The project development process for floating solar is the same as it would be for ground mount or rooftop with the following differences:

- Bathymetric surveys are utilised to map

The 8.9MW Canoe Brook floating solar system in New Jersey, US

Credit: Ciel & Terre

Guidelines and standards for floating solar

Since there is no generally accepted engineering standards or guidelines specifically for designing FPV, one should look at what current standards are utilised by the supplier and how they were applied specifically considering site requirements, followed by a review of how third-party certifications confirming the system will perform and survive for the expected life of the project. Examples of some standards references or guidelines that might be useful to review when pursuing a floating solar project includes:

- Bureau Veritas' NI 605 DT R00, which was developed for use with foundations and anchoring of offshore structures.
- DNV-GL has developed a Recommended Practice, DNVGL-RP-0584, for the design, development and operation of floating photovoltaic systems.
- World Bank's 'Where Sun Meets Water, Floating Solar Handbook for Practitioners'
- American Society of Civil Engineers (ASCE) design codes, while not pertaining to floating solar, do provide guidance for structures to withstand wind, snow load and similar conditions.

underwater bottom terrain to inform array placements and necessary cable slack.

- Decisions occur on walkway access versus service boats for ongoing operations and maintenance needs.
- Key design factors revolve around water conditions and weather resilience in the chosen location, and anchoring and float spacing adjustments are made according to allowable wave heights and surface currents.

Floatovoltaic systems are not immune to the effects of weather and natural catastrophes. As water levels periodically drop or seasonal ice thaws, low-sitting floating platforms that are properly moored can come to rest securely on exposed lakebeds, as long as the tilt angle between floats does not exceed 15 degrees. These assets are not installed with trackers and do not typically have hail stow capability. To better protect from hail, enhanced tempered and thick glass is utilised. Integrated lightning rods and fire suppression equipment provide further safeguards.

Recent major global projects include the 8.9MW Canoe Brook installation in New Jersey. Meanwhile, Dezhou, China now hosts the world's largest operational floatovoltaic site at over 320MW, exemplifying rapid adoption across Asia as the industry matures.

Risk management & loss control

For covering unfamiliar technologies like floatovoltaics, clearly explaining the engineering basis and focusing on embedded risk mitigation strategies is key for securing insurer participation across critical property, equipment breakdown and other coverage lines. Once a project receives the go-ahead, collaboration with clients to outline potential equipment breakdown (PEB) risks is an important step to address how project risks were addressed from the design phase through the operational life of the asset. This collaborative communication ensures all stakeholders understand preventative preparations enabling performance.

In preparing for a recent client's initial floatovoltaic project, Willis Towers Watson's renewable energy team held discussions with various insurers' underwriters and risk engineers regarding their perspectives on this asset type. It became evident that floating PV was considered a new and unfamiliar solar application for most domestic insurance companies, especially at the utility scales seen globally. Most US projects are below 10MW, with some less than 1MW, while Asia has commissioned floating solar projects of 300MW-plus.

Concurrent with the insurer dialogues, conversations also occurred with several floating solar system providers to understand their engineering, testing and installation approaches. Perspectives were shared around the important role brokers and insurers play in supporting project developers to obtain appropriate insurance coverage and how system vendors can facilitate that process.

To further the understanding of floatovoltaic system risks, below is a review of the potential equipment breakdown exposures floating solar presents:

The mooring or anchoring system is the primary risk differentiator compared to conventional solar installations. The design and component materials must be tailored to characteristics unique to the site, including modelling conservative wind, wave and flood assumptions when engineering mooring and anchor durability specifications. In-depth geotechnical studies help determine the optimal anchoring approach, whether submerged moorings, shoreline attachments, or a combination. Numerous techniques exist – such as deadweight anchors, driven screw piles or anchored perimeter pillars – each with merits and downsides. The flexible lines linking to these anchor points face exposures too, with options like steel wire cable, chains and high-performance ropes to select appropriately. The modular flotation system warrants similar context-specific planning, with materials ranging from high-density polyethylene to composites forming the bases that ultimately underpin the solar arrays. Hardware and connections must prove corrosion-resistant while supporting loads. Even access walkways and equipment transport barges require deliberation to enable ongoing operations and maintenance. By tailoring these foundations to the conditions at hand, the resultant reliability fundamentally impacts overall system viability.

The photovoltaic panels themselves resemble models utilised for ground-mounted installations, although tailored racking, mounting and support hardware attaches instead to the floating platforms. Those component materials must withstand corrosion from the surrounding environment, with options including marine-grade aluminium, stainless steel, coated carbon steel, fiberglass reinforced plastics, polypropylene and HDPE. Trackers and hail stow capability are generally not an option with this system type, which introduces some increased weather vulnerability. However, FPV is generally constructed in areas with low hail risk.

The electronic components resemble standard ground-mount solar but warrant customisations for aquatic conditions. Inverters, transformers, junction boxes, combiners, monitoring systems and most wiring use comparable components, albeit with specialised enclosures and connectors. Central inverter stations and transformers can float on equipment barges, and string inverters can be placed on the array. Particular considerations apply for routing cables – options include cable trays suspended above water or underwater marine-grade cables. While the layout mimics land-based equipment, the nuances of transmitting electricity from floating generation assets to distant interconnections require thoughtful adaptations without compromising safety or production.

Risk considerations

Natural catastrophes pose immense threats to floatovoltaics that proper siting and engineering design strive to withstand. Detailed hazard models determine expected peak wind, precipitation, seismic activity and flood levels that establish structural specifications. Still, failures leading to detached arrays or connecting cable breaks trigger revenue and equipment loss potentials. Innovation continues to protect this asset class: anchoring improvements continue to better adapt to rising waters, while ongoing surge suppression advances seek to limit lightning-sparked fire risks. Working with insurers as the technology continues to evolve will help create customised terms for this asset class.

Ongoing O&M proves equally vital for preserving floatovoltaic functionality, albeit with some complications introduced by the aquatic conditions. Technician access usually necessitates boats or floating bridges, adding costs and weather-dependent delays. The lack of trackers avoids some moving part repairs, but static positioning increases weather exposure. Reliable performance necessitates remote monitoring to enable rapid diagnostics and response coordination for identified faults. Insurers can further aid resilience by requiring ample replacement component stocks and technician training programmes.

General corrosion and erosion risks also multiply with FPV, necessitating durable materials selections and coatings. Pre-deployment water analysis determines precise chemical properties to model deterioration rates over decades and enables the specification of appropriate panel compounds and protective sealants. Ultraviolet radiation steadily degrades plastics, cabling jackets, and rubber without proper additive shields. Regular cleaning and scheduled underwater surveys can help confirm minimal accretion or insulation damage. Insurers complement via policy terms stipulating these inspection, testing and replacement frequencies contractually.

Insuring floatovoltaics

New and rapidly evolving technologies are still niche in the PV industry, and dealing with the associated emerging risks has become an accepted cost of progress. This has proven to be quite challenging for the insurance industry, however, especially in predicting the loss profiles of new technology which has not had substantial time in the field. With any asset, the carrier's mandate is to understand the losses that should be expected in a given year, and what losses are in extreme events, such as 1 in 500-year flood or fire events. This presents challenges, especially in the use of natural catastrophe, or 'nat cat' modelling software, which only supports modelling of certain types of constructions and can be slow to incorporate new technologies.

Without historical loss data and predictions from modelling, insurers have to get creative in the way they think about these emerging risks. The brightest and forward-thinking insurers turn to existing research and sometimes conduct their own.

Battery energy storage systems, or BESS, serve as a great example of how carriers get their arms around cutting-edge continuously evolving technology. Diligent underwriters have worked with the industry and modelled data to understand what factors lead to thermal runaway events and how certain chemistries are more prone to thermal events than others. As another example,

Case study: claims scenario

While advances continue improving durability against damage, floatovoltaics still present unique claims scenarios. Defective anchoring systems make arrays susceptible to panel detachments from high winds or large waves. Usually occurring during storms, they can also fail gradually over time from undiagnosed flaws and unnoticed corrosion. kWh Analytics currently insures a floating solar project utilising high-quality equipment from industry leader Ciel & Terre. The anchoring system specs were reviewed to gain comfort over the system's resilience to wind load and changes in water level. Site-specific considerations were also made for the anchoring and mooring system implementation. The anchoring utilizes galvanized steel shackles, cables, chains and stabilisers to prevent corrosion and account for water level changes.

Another vulnerable period is maintenance activities when accessing equipment on the water, which exposes technicians and parts to greater environmental hazards. Even theft, vandalism, or negligence, also known as attritional risks, increases during construction before safeguards are fully implemented. Other scenarios like snow load accumulations stressing structural integrity or cabling destruction from extended UV radiation exposure underscore the importance of insurance protection. The kWh-insured site includes a floating bridge for routine maintenance access to the floating-ballasted array and supported PV equipment.

Overall, the insured's robust design and installation, coupled with the manufacturer's expertise, provided strong resiliency measures that enable comprehensive underwriting analysis. Insuring this risk is an opportunity to cover best-in-class emerging technology and support the future growth of floatovoltaics.

kWh Analytics currently insures a floating solar project using equipment from Ciel & Terre

hail stow trackers were introduced to the industry as a hail risk mitigator. Considering this resilience effort in underwriting included calculating the kinetic energy reduction due to the tilt angle of the panel when hail strikes, taking this into account along with lab testing results on different modules' glass thicknesses. Each new type of technology requires new methods to evaluate the risk, which can be used in conjunction with any loss data available.

kWh Analytics employs data scientists, some with engineering and physical science backgrounds, to work with underwriters to consider all the data and evidence as a whole when writing these risks. This method is applied to floatovoltaics as well, in understanding the effects of natural catastrophes on these systems, extrapolating loss data from other parts of the world to apply to US assets, and determining maintenance, replacement and business interruption costs.

Insurance policies for floatovoltaics projects diverge in critical ways from standard solar development coverage given the distinctive nature of these water surface-based systems. As an emerging technology, inadequate historical data on damage frequency and claims experience further complicates reliable risk assessment. Insurers must collaborate closely with developers and equipment manufacturers to institute loss control stipulations and craft policy terms that balance premiums with adequate protections.

The effect of major natural catastrophes on these systems is an important consideration in underwriting floatovoltaics. From the anchoring and moorings securing arrays on the water surface to the transmission cables underneath, insurers must evaluate a range of site-specific perils:

Flood: The anchoring and mooring systems are designed to adjust to varying water levels, providing resiliency against flood damage. This enables more favourable flood coverage compared to ground-mount solar sites. The anchorings also account for lateral wind and water flow forces.

Earthquake: The anchoring system's capacity to handle changes in water levels also provides secondary protection against lateral seismic activity and horizontal loads. This resiliency can allow for enhanced earthquake policy terms.

Hail: Most floatovoltaic installations utilise fixed-tilt racking, which leaves arrays more exposed to hail strikes since stow capabilities are not available. Hail coverage may need to account for this increased vulnerability.

Fire: Accessing floating arrays far from shore poses challenges for fire response, containing outbreaks, and controlling spread across water. Some sites employ a bridge to the island, allowing for easier access. Insurers may limit fire coverage or impose specific loss control measures to mitigate this risk.

Insurers can also reference other marine projects when evaluating floatovoltaics since certain characteristics overlap. This includes assessing resilience measures for floating platforms and docks, elevation tolerances for electrical components, and specialised considerations for fire protection and O&M services. As the floatovoltaics insurance market matures in step with broader industry growth, compiling data around actual losses will clarify how these assets perform through extreme weather and lifecycles. This will enable the fine-tuning of underwriting guidelines as challenges are conquered but new vulnerabilities also inevitably emerge with any pioneering technology.

As an emerging technology, education around the intricacies of floatovoltaics is imperative for insurance brokers and underwriters new to this sector. With rapid global growth projected in floating solar installations, gaining understanding now prepares stakeholders for the wave of new projects seeking insurance policies customised to their distinctive needs.

Proactively engaging with asset owners and manufacturers allows brokers and carriers to best advise clients on properly structuring risk management programs. For carriers, understanding the nuances enables appropriate policy terms, conditions and pricing that matches the risk profile. While risk mitigation measures around priority perils continue maturing, diligence today will allow insurers to incorporate best practices.

Floating PV represents an exceptionally promising market expansion opportunity for solar energy. By siting photovoltaic systems on non-usable bodies of water rather than premium real estate, this technology can unlock additional renewable generation capacity critically needed for sustainability targets, often close to where the electrical demand is needed.

Though floating PV only makes up a small portion of today's renewable energy fleet, rapid cost improvements coupled with supportive government incentives position this sector for immense growth in suitable regions worldwide.

Yet as an emerging field still maturing, risks remain that may deter uptake if not adequately addressed. Insurers play a vital role not just in comprehensively evaluating floatovoltaic vulnerabilities, but also collaborating closely with developers to promote safety and resilience through loss control stipulations. Leveraging data science, engineering expertise and lessons from analogous assets enables shaping prudent underwriting guidance during this formative market phase. Adoption of best practices will allow progressive improvement of insurance terms as statistical credibility accumulates over time.

The long-term outlook remains bright for floatovoltaics contributing materially to de-carbonization. However, maintaining sustainable expansion requires asset owners, brokers and carriers to collaborate on the growth of this technology frontier. The efforts undertaken today to understand the intricacies of floatovoltaics will establish foundations for successfully scaling this innovative solar domain, unlocking its immense potential to combat climate change.

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Challenges and solutions in inverter repowering

Inverters | Replacing outdated inverters can significantly boost the yield of a PV power plant and rectify equipment failures. Jörn Carstensen of Germany-based greentech looks at the technical, financial and logistical considerations involved in a successful inverter repowering project

The replacement of inverters is not only important in the case of defects, but it can also significantly increase the yield of the plant and extend a solar farm's lifetime beyond the feed-in-tariff (FiT) period. To be successful, the repowering project should be well planned and closely monitored.

Inverters are the heart of the PV plant. They have interfaces to all relevant areas of the electrical system and make the electricity produced by the solar modules usable for the grid at the correct specification. In addition, they provide information about yield data or possible faults. However, over time technical weaknesses can occur which will lead to a reduction in the performance of the system, increasing repair costs and more frequent maintenance intervals. In recent years, many of the components for PV systems have not only become cheaper but also more efficient and capable of generating a yield increase of between 3% and 5% with the same capacity. These developments may justify an investment in new inverter models even if the existing ones are still running without issues.

Successful repowering requires careful engineering and design

Every inverter replacement requires close coordination with the responsible grid operator. If necessary, a plant certificate or the appropriate protection and control systems must be retrofitted. Furthermore, inverter repowering during the FiT or any other compensation period is a good opportunity to prepare the system for continued operation afterward. In many cases, the additional yield compensates for the repowering costs incurred – this is especially true for older plants that have only a short remaining term under the incentive scheme but receive high tariffs. Projects can thus pay for themselves after only two to three years. In addition, manufacturer guarantees and warranties for the new components are renewed.

Example 1: Reverse use of a DC combiner box (DCCB)

In this example, the main DC cables of the module generator led centrally to the inverter station. However, the only available inverter model compatible with the original inverter power and voltage level of the modules did not have a central DC input, but only several string inputs. In consultation with the inverter manufacturer, a DCCB was designed that divides the main DC cable into several individual strings according to the inverter's specifications. This meant an additional component and installation effort but prevented a significantly more costly rewiring of the entire system.

AC integration

On the AC side, it also makes sense to build on the current infrastructure and connect the inverters to the existing low-voltage (LV) main distribution and AC cable system. Since the power of the new inverters usually does not exceed that of the existing ones, cable cross-sections and fuses are usually compatible. The reconstruction of the LVAC system is not only time-consuming and expensive, but additional risks would also arise due to the opening of new construction areas at the plant. Different voltage levels of the inverters may also have to be considered on the AC side. Today, the nominal voltage is predominantly 400 or 800 volts. When replacing an inverter, the applied AC voltage must be checked and, if necessary, adjusted via a tap changer on the transformer.

Plant communication system

To ensure the performance of the plant, a functioning plant monitoring system is indispensable. Data loggers connected to the generation units and plant sensors collect corresponding data and forward it to a monitoring portal. However, different models of inverters have different data protocols. In the case of a partial repowering, the data logger must therefore be able to process and send the protocols of both the old and the new inverters. In the extension, it is then necessary to include the new components in the monitoring software and reconfigure alarms if necessary.

However, it is not only data from the components themselves that must be collected, stored and forwarded – it is crucial that the inverters react to the active power control of the grid operator or PPA provider and are also able to implement specifications with regard to reactive power. In the event of a replacement, this control system must be rebuilt, set up and tested. Here, it is important to coordinate closely with the responsible grid operator.

Mechanical installation

Changing from old to new string inverters in the field is usually not an issue from a mechanical point of view. The regular installation requirements and structural aspects need to be considered.

Central inverters and other technical components are often installed in fixed stations on the plant site and are protected from external influences. Dismantled inverters must be disposed of properly – recycling proceeds can certainly be achieved here. Before installing the new models, the available space must be checked as manufacturers have different installation requirements, for example regarding the distance between the units and the walls of the station. Depending on the situation, additional DC or AC combiner boxes may have to be accommodated and the cables routed accordingly so that they comply with the specified bending radii.

Credit: greentech

Example 2: Using the outside wall of an inverter station

When replacing old inverters with new string inverters, according to the manufacturer's specification, more space was needed than was available in the station. As a solution, the outside of the station was also used. Cables were led through the wall into the cable basement of the station. Since the area was not fenced, the outside use required not only weather protection but also additional access protection. As this changed the external appearance of the facility, this solution was agreed with the local authorities beforehand.

Credit: greentech

Consider existing infrastructure when choosing new inverters

New inverters should be as compatible as possible with the existing infrastructure – otherwise, the costs quickly rise to uneconomical levels. It often makes sense to replace central inverters with large string inverters or to replace many old small string inverters with a few newer, large ones. However, this also means that all interfaces to other system components, such as cables or fuses, must be validated and adapted if necessary.

DC integration

Older systems often have a lower system voltage on the generator side than newer systems. Depending on the age of the system, new inverters must therefore also be able to operate at that lower voltage level. This alone can limit the selection of suitable products. In older systems, central inverters with complex wiring and cabling of the module strings up to the generator connection are often installed, which are barely compatible with newer models. However, the structure and the wiring of the generator side are usually not changed when replacing the inverter. This is not only for cost reasons alone. The original DC dimensioning should not be exceeded, otherwise there is a risk that the tariff/ROC payments will be withdrawn. Nevertheless, optimisations of the system can be achieved through the process of repowering if, for example, module strings are connected directly on the new inverters and previously used combiner boxes are omitted. This reduces possible sources of error and future maintenance requirements.

It can be more difficult when converting from central inverters to string inverters as the DC main cables cannot always be connected directly to voltage-compatible devices. In cases such as this, an individual solution must be found.

A profitability and sensitivity analysis brings transparency to the economic potential of a proposed inverter repowering

Business planning

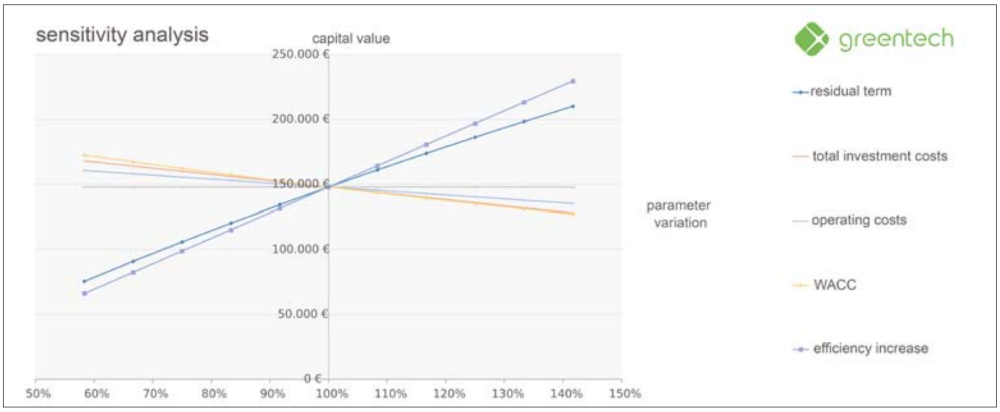
For the investor, solid planning also includes a transparent overview of the economic potential of an inverter repowering. Here, reliable key figures within the framework of a profitability and sensitivity analysis help. It does not only show the repowering costs and benefits – it also provides the impact of possible deviations. Is an investment still worthwhile if, instead of the assumed 3% increase in yield, only 2.5% is achieved? Or if the costs of the project turn out to be 10% higher than calculated?

Implementation

The implementation of every construction project must be closely monitored. In the case of inverter repowering, this begins with checking the design documents for completeness and plausibility. At least three visits for quality control should take place on site. At the start of construction, the engineering, the installation schedule and any special points should be discussed. The risk assessment and method statement should be verified and signed by all parties involved. In a second meeting during the construction phase, the focus lies on the implementation quality. The design documents are compared with the situation on site – if conditions differ, points may have to be decided instantly. Finally, the work needs to be accepted. In addition to checking the construction work and compliance with the manufacturer's specifications, this also includes functional testing of generation and communication as well as checking the technical documentation and measurement protocols.

Follow-up

To verify that the planned benefit of a repowering project really happens, a comprehensive evaluation is carried out after about one year of operation. If all inverters are replaced, this is not so easy, as a suitable reference is missing, and fluctuating irradiation and temperature conditions make an analysis difficult. However, innovative evaluation methods such as a power curve analysis are suitable for this and can identify also smaller deviations reliably and by this provide an objective basis for evaluating the measure. After the completion of the repowering, it is time to discuss the maintenance scope of the new inverters with the operator as well as a possible adjustment of the O&M fee. ■



Credit: greentech

Authors

Jörn Carstensen joined greentech in 2014 as sales manager and has played a key role in shaping the company's continuous growth path. In addition to entering the UK market, he built up the engineering and technical advisory division. Today, as managing director, Jörn is responsible not only for business development but also for the operational areas of plant operations, field service as well as engineering and technical advisory. Prior to greentech, Jörn worked for the Conergy Group from 2006 to 2014, including in the areas of post-merger integration as well as corporate and business development. greentech is an integrated photovoltaic specialist, with a range of services covering project development, design, construction and operational management of photovoltaic power plants in selected European markets. In addition, greentech offers services in the fields of quality assurance, yield maximisation, financing and electricity marketing.

Pre-assembled solar bridges energy gaps and challenges large-scale traditions

Plug-and-play | Cost and risk factors can make countries facing energy access issues the most difficult for developers to build solar projects, despite their huge potential. Tom Kenning reports on two plug-and-play solutions that may provide a solution in off-grid locations

Most PV system contracts involve solar systems being in one location for 25 years, but a new model of leasing re-deployable solar PV systems could offer flexibility to off-grid applications where power is only needed for a few years, while countries with electricity access problems could use these systems to bridge emergency energy gaps.

Not all geographies and markets suit the traditional large-scale PV model that is proliferating across the globe. Utilities in under-developed markets, for example in Sub-Saharan Africa and pockets of Asia and Latin America, are often not able to commit financially and strategically to longer contracts.

The solution may lie in prefabricated solar systems where the mounting structures and solar panels are assembled in an off-site factory with a design that allows for a quick and easy installation process on site, as well as redeployment further down the line.

Only a handful of companies are offering such solutions at present, but those approached by PV Tech Power believe these models will become mainstream and even dominate in a few years due to the flexibility, lower labour costs and ease of construction advantages of a modular and re-deployable solution.

This article looks at two different approaches to pre-assembled PV systems: firstly, the solar-plus-storage 'Release' solution from Norwegian clean energy firm Scatec, which includes a prefabricated solar tracker-based structure called 'Nomad' built by UK-based firm Cambridge Energy; and secondly, Australian firm 5B's prefabricated and pre-wired modular 48-50kW fixed-tilt array known as 'Maverick' that focuses on energy density and high-speed deployment.

Credit: Scatec

Scatec's solar-plus-storage system using prefabricated solar tracker structures from Cambridge Energy

Scatec's plug-and-play Release

Scatec's Release solution involves financing and renting out plug-and-play solar systems on a shorter timeframe than the typical 25-year power purchase agreement (PPA). This makes solar available to off-takers who might not have the financial strength to make such long-term commitments and to those with temporary power needs such as a mine that may only need a decade of electricity.

Although Cambridge Energy's 'Nomad' system provides the backbone of the Release solution, it is Scatec that takes the risk of funding, designing and installing the projects. It also adds an energy storage component to create integrated power plants that can perform energy-as-a-service (EaaS) tasks. The aim is to reduce the need for setting up complicated structures with thousands of workers onsite, while designing in the most efficient transport density and simplest installation basis to avoid as much as possible the use of cranes and machines.

Hans Olav Kvalvaag, CEO of Release by Scatec, tells PV Tech Power that the company was attracted to the tracker-based option primarily because the equipment has the flexibility to be easily and quickly dismantled and deployed elsewhere, but also since the trackers cater to its preferred bifacial modules.

Modular solution

Prefabricated solutions are easier and quicker to install than conventional solar structures, which use large amounts of concrete and require an EPC operation to perform piling when installing the structures on site. Not needing lots of workers, subcontractors and machinery is particularly advantageous for smaller-scale and off-grid installations where sourcing a large workforce can be difficult, says Kvalvaag.

"We believe strongly that prefabricated solutions will be an important step change in developing the smaller-scale projects and making it much simpler," adds Kvalvaag. "We see some others that are trying to do the same and we believe that this will come more and more."

Even the largest scale projects may eventually start to incorporate these pre-assembled solutions because the "beauty of solar" is its modularity where the same solutions can fit both large and small-scale projects, claims Kvalvaag. However, the major PV module makers at present are too focused on tight margins and cost efficiency to put time into developing these pre-assembled solutions, Kvalvaag believes. The same goes for the tracking device giants such as NEXTracker, adds Kvalvaag, who for now are focused on delivering gigawatts of product.

Renting solar like renting a car

Scatec allows mines, big construction sites and other off-grid operations to rent the Release solution for, say, five years, and at the end of that period, the client may decide to increase or reduce the capacity as it expands or draws back on its operations. This is facilitated by the modular flexibility of Release which comes in ~1MW blocks. The energy storage components can also be scaled up or down in a similar way. While traditional IPPs engage in standard PPAs involving lenders and multiple financing parties, in this case, Scatec funds and rents out the project.

"It's like renting a car," says Kvalvaag. "You call us and say you want to extend, then we do that. That's the flexibility we want to offer."

African utilities

Scatec has a wealth of experience of building utility-scale solar in Sub-Saharan Africa and with Release it plans to target both African utilities and mining operations for two different reasons. Mining operation lifetimes may be far shorter than 25 years and need flexibility on capacity, while African utilities lack institutional capacity and capabilities to sign up to an IPP solution for 25 years.

"They don't have the balance sheet, the financial strength, or the ability to give the sovereign guarantees required," adds Kvalvaag – noting that the pre-assembled Release system, which is comparatively more expensive due to its shorter timeframes, allows for a game-changing level of flexibility.

For this reason, Release has attracted finance from the World Bank Group investment arm, the International Finance Corporation (IFC), along with Climate Fund Managers, a Netherland-based fund manager specialising in climate-focused finance. "What we all want to offer is affordable and reliable power and to reduce and replace the diesel and fuel consumption that we see across Africa," says Kvalvaag.

Several African countries use contracted diesel generation for emergency power, which not only has high environmental impacts but also has significant cashflow repercussions for the governments, says Sarvesh Suri, IFC's regional industry director, infrastructure and natural resources, Africa. Such states then become entirely susceptible to the high charges inflicted by emergency diesel power providers, when diesel costs are already on the higher end.

Instead, the Release system can deliver power rapidly on an emergency basis with these short-term lease agreements and Suri says some of the tariffs agreed on the leases with Scatec are similar to what an IPP would be signing for to on a 20-year PPA, so the country in question also benefits.

"They are assuming that after five years the product would be so good that the countries will continue to renew the leases," says Suri. "In the case they can't, they can rapidly take the assets and deploy them in another situation. That allows them to amortise the lease payment over a longer period than just the term of the lease and still keep the cost competitive."

The Release system can be installed at a rate of 1-2MW per week with 10-15 labourers and Kvalvaag says having fewer workers and a prefabricated system allows for much better control of a project, which then helps to address security issues. For example, Scatec is starting to work on projects in less secure and challenging markets such as Chad and Liberia, where it is also hard to find external EPCs to build projects.

'Democratising access to solar'

At scale, prefabricated solar solutions have a total capex that is 20-30% cheaper than traditional solar, claims Tom Miller, CEO of Cambridge Energy, which produces the Nomad system. On one hand, he likens the re-deployable PV Release model to turning real estate into a car fleet. On the other, he compares it to Lego given its high level of modular flexibility. This gives the product unique suitability for installation in challenging, remote geographies that traditional players tend to avoid.

"Most people are scared of these types of projects often in locations where there's a lot of excess risk because of sovereign risk," says Miller.

Cambridge Energy started by deliberately targeting the hardest places to install projects so that scaling from that point onwards would naturally be far easier. Nomad systems are already deployed in the Atacama Desert in Argentina, the Yukon in Canada, Norway and Sub-Saharan Africa.

Nomad decreases many traditional barriers to installation such as sourcing bottlenecks, transport, and risk mitigation. Miller claims this makes solar power available to many more players rather than just

Release put through its paces in Cameroon

Scatec has recently demonstrated the problem-solving ability of its prefabricated Release system by deploying 36MW of its solar tracker structures on a short-term lease to Cameroon's national electric utility ENEO. The African nation's energy system had suffered from a severe drop in water levels at the 72MW Lagdo dam, one of its critical power sources. The Release systems were connected to Cameroon's Northern Interconnected Network grid, which suffers frequent outages, but as a flexible renewable energy solution, the Release system is claimed to able to bridge this energy gap by both augmenting the power supply from the dam and ensuring continuous electricity.

Scatec's Release system installed in Cameroon to bridge electricity shortfalls

concentrated in the hands of a few large companies that deploy at mega-scale on the grids, a process which he describes as "democratising access to solar".

"The applications are endless if it's 30kW or more: water pumping, mines, processing, hospitals," he adds. Mines, for example, can easily offset their expensive diesel costs while not having to operate the energy system themselves.

World Bank's first risk mitigation facility

Both the IFC and Climate Fund Managers have financed the growth ambitions of Release. IFC was attracted by the innovative contracting arrangements on this flexible PV solution and Sarvesh Suri says it can reduce the time of concept to delivery of a project from 3-5 years to 9-15 months. Furthermore, Release has been deployed "in some of the most remote and fragile environments in Africa and all over the world."

IFC provided capital alongside blending the use of concessional funds from its sister agency IDA Private Sector Window to provide a package that reduces the risk for investors but also allows projects of this innovative nature to go forward. This was the first time the World Bank Group's board approved what it calls a risk mitigation facility, which is a liquidity facility on the balance sheet of IDA.

There's no reason why these prefabricated models can't proliferate into the mainstream solar landscape both in the off-grid and large-scale sectors, adds Suri. The reduction in cost of solar cells over the last decade has made distributed energy a key part of the energy access story in Africa and this is why the IFC has started to focus heavily on distributed generation. Coupled with the reduced costs of smart and remote metering and monitoring solutions, it has become far more scalable.

Having more flexibility in the financing helps to decrease financing costs and therefore to offer cheaper power, says Miller.

"In Africa, more than 60% of the PPA price is determined by the cost of capital, which is effectively a function of risk," he adds. "So, if you can decrease risk alone, you're doing more for helping the power price than you are by optimising for a cent per watt here and there on the structure. This is the one area that's poorly understood, and that Scatec understands very well.

"This flexibility and leasing in Africa and remote [areas] is incredibly valuable because it's about bringing sophisticated developed-world financing and putting it into places where traditionally you could never consult."

Maverick energy density

Australian firm 5B has a prefabricated plug-and-play 50kW array, called 'Maverick', which is assembled in an off-site factory, shipped efficiently in containers to site and then both rapidly and labour-efficiently rolled out on solar sites with capacities ranging from hundreds of kilowatts up to hundreds of megawatts.

The 50kW arrays – made up of 90 standard solar modules – are folded up for transport then unfolded down to a 10-degree tilt in either direction, notionally with an East-West orientation, explains Simeon Baker-Finch, CTO, 5B. The firm has assembly locations in Australia and Vietnam, with a third location soon to be revealed, and its Maverick systems have been deployed in Australia, Latin America, Chile, and Panama.

A key difference is that the 5B Maverick system is ground-mount while Cambridge Energy's Nomad uses trackers, but both systems enjoy similar benefits of prefabrication.

For example, the Maverick has the benefits of controlling safety and quality in a factory and Baker-Finch claims it is three times more labour efficient and significantly faster to deploy than standard structures. Energy density, however, is one of the main advantages of the Maverick and Baker-Finch claims it can generate roughly twice as much energy per unit area of land compared to single-axis trackers, which are typically more spread out.

"It's a trade off," adds Baker-Finch. "The Maverick chooses to optimise for land efficiency as opposed to module efficiency."

The energy density approach makes sense as modules become less and less expensive particularly in terms of optimising use of space, says Baker-Finch, whereas Miller highlights the importance of resource efficiency and the benefits of squeezing the most out of every single module rather than the land. Nonetheless, Baker-Finch believes the energy density route will become increasingly common in applications involving co-location with industrial loads, like hydrogen electrolysers or in the production of green steel.

Again, the Maverick is very easy to pick up and deploy elsewhere. For example, there were plans for half of a large site in Panama to be redeveloped in two years, with the other half remaining in situ. So 5B deployed a large solar array and then moved the second half on to a cleared area of the site later on. Baker-Finch says this reduces the stranded asset risk for a financier of an energy access project that has less certainty about consistent revenue. Furthermore, if miners were to become interested in the land beneath a solar array, this flexibility at least gives the option to relocate.

The Maverick is also aerodynamic and set low to the ground giving it a wind resilience that makes it suitable for Cyclonic zones such as the Gulf Coast of the US, Florida, and parts of Northern Australia. Its shallow ground penetration and function without cable trenching also make it suitable in areas with difficult terrain such as landfills, waste facilities, reclaimed land, tailings dams, rock dumps and mines.

Ultimately at a time where the PV industry is facing labour shortages, pre-assembled PV systems' ability to significantly reduce workforce numbers must be turning heads in all scales of solar, while the distributed generation sector could be boosted by these novel deployment, scaling and financing flexibilities.

The 5B Maverick being unfolded in semi-autonomous deployment in Atacama, Chile

Credit: 5B

On a firm footing

Foundations | The foundations of a solar project offer multiple opportunities for driving down system costs. Arash Yazdani of PRI Engineering describes some of the key steps involved in investigating the specific conditions of a project site and developing a foundation design that will stand the test of time

Credit: PRI Engineering

The foundations of a PV power plant are quite literally that – the footing on which a project is built and, as such, a vital ingredient in its longevity and profitability, or otherwise. The foundation system provides the primary interaction between the site and its specific conditions, and the PV project's racking system and modules. Any movement or failure of this component will affect the entire system, leading to costly change orders and overruns during construction and even failures during operation.

Optimal foundation design is therefore a potentially untapped source of savings in the overall costs of a PV project. Doing it correctly and thoroughly upfront may take a little more time and initial investment at the outset, but it's an investment that will provide an outsized value in proportion to the costs avoided or saved further down the line.

It is critical for proper foundation design to take into account the specifics of a project site, enabling the structure to be optimised in line with the many variabilities of the subsurface conditions found on the site. Often designers employ a "one size fits all" philosophy to foundation design, but unlike manufactured materials, you cannot order set soil properties; rather, your foundation must be designed to match the site's specific subsurface conditions. Optimising as the site varies could allow you, for example, to reduce the overall length or size of the foundation in areas where denser soils or other more favourable conditions are encountered. As typical solar farms contain a large number of foundation elements, the cost savings which could be gained from the minor optimisation of a pile length of just 0.3m could run into millions of dollars.

Site-specific design

When designing a solar project, we let the site determine the foundations and layout we need. An out-of-the-box solution or kit may work well on smaller sites with low variability. In contrast, large-scale solar projects require intelligent geotechnical design to minimise the upfront investment and decrease the time until your return on investment. Key considerations in finalising a design are the climate found in the project area, the project's scale, site subsurface conditions and the optimal type of foundation that will best suit these parameters.

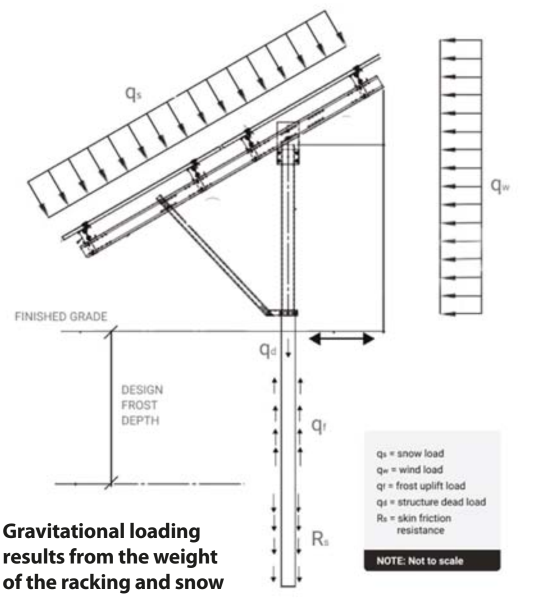
Foundations are an untapped source of cost savings in PV power plants

Climate considerations

Before investigating a site's soil conditions, we typically analyse the worst-case scenarios relating to a site's climate. For a solar project, three primary climate-related considerations can result in minor to severe damage: frost and wind uplift, snow accumulation on the system, gravitational loading (or the dead load) and seismic activity. Proper consideration of the loading stresses these can put on solar racking foundations can help prevent costly repairs or a complete rebuild.

For frost and wind uplift, the design principles that prevent them are largely the same. When frost or wind uplift loads increase, the two main ways to compensate are to embed the foundation deeper or increase the size of the foundation. Other measures to counteract frost uplift include the installation of a frost sleeve, which can help reduce the frost uplift to 30% and is an economical solution in a site with weak soils or where long colder winters are anticipated.

Gravitational loading is the result of the weight of the racking system and, in colder regions, resting snow bearing down on the foundation. Both can lead to problems if there is variation in the



Gravitational loading results from the weight of the racking and snow

Credit: PRI Engineering

movement of adjacent piles as some settle or heave more than the adjacent foundation elements in the same table. This can lead to stresses on the racking, and permanent deformation in the structural members and even the PV modules themselves.

Seismic loading is not a concern in all areas, and even for projects in regions with regular seismic activity, the risk is still relatively minor due to the light weight of the structures. The main difference between seismic loading and gravitational loading and wind and frost uplift is the cyclical oscillations over an extended period that may result in fatigue, particularly if using aluminium for structural members. Since PV racking structures are relatively light and low to the ground, seismic activity typically does not exceed the racking tolerances, except when auxiliary equipment such as combiners, inverters or even motors for single-axis trackers are attached to the foundation element. As with other loading, larger foundations help compensate for seismic loading.

Project scale

As the size of a solar project increases, the potential for site variations increases as well as possible complex subsurface conditions. Larger projects also have more foundation elements, meaning more risk. But they also mean larger budgets which means budget allocations to engineering could be greater.

For a PV system above 600kW, a comprehensive geotechnical investigation is necessary. In addition to soil testing onsite, we would include in-situ pile testing and refine the recommended designs to the particular conditions on-site. This enables solar project developers to reduce steel costs and have greater confidence in the performance of the foundations across the site.

Geotechnical survey

With respect to your ability to control a construction project, the most variability will frequently come from the earthworks. This variability is often attributed to natural occurrences, due to depositional processes such as erosion, glaciation, volcanism, or different fluvial processes that create conditions that can alter designs in a very drastic fashion. Variability typically means risk, and a geotechnical investigation completed by a qualified geotechnical engineer, familiar with the local geological depositions and these materials' engineering properties, is the most effective way to complete an appropriate foundation pile design for a racking system and thus mitigate and manage site risks. Results of detailed investigations should be included for potential contractors at the bidding phase as it will typically mean you will be getting more competitive pricing and taking on less risk.

Inadequate geotechnical investigation and foundation testing prior to the bidding phase could lead to highly complex subsurface conditions not being discovered. These unknowns typically arise due to the variability of site subsurface conditions that were not discovered due to minimal information being collected, or when supplemental information may have been needed but was not collected – typically due to budgets, but also due to schedule constraints or just an overall misunderstanding of the risk. Unknowns can lead to change orders during construction, which will increase costs.

Subsurface conditions can vary drastically from site to site, and depending on the subsurface conditions, many of the design considerations may change accordingly. Some conditions that must be determined are the overall gradation of the site soils to develop an understanding of the required analysis requirements and engineering properties for encountered materials. The presence of obstructions or other deleterious materials such as organic-rich materials, which are traditionally problematic for all types of foundations, must be assessed. And the overall excavation/boring stabilities and groundwater conditions must also be assessed.

These can influence several parameters relating to the design of the foundation, such as the adfreeze pressures, frost design depths, corrosive nature, overall resistance to design loads, and constructability. All of these parameters are affected to a significant extent by the site's soil classification, which broadly falls into two categories: coarse-grained (predominantly sands and gravels) or fine-grained (predominantly silts and clays).

As an example, with adfreeze pressure – the pressure generated from water freezing within the pores of the soil – a coarse-grained material generally holds more water in its pores because of a higher porosity and therefore can have a higher adfreeze pressure compared to fine-grained material which has a lower porosity and therefore a lower adfreeze pressure.

Soil composition also affects frost penetration depths and thus vulnerability to frost uplift: gravelly sands, which are more porous and consequently have a higher void ratio, are more susceptible to frost penetration when compared to finer silts, clays, and fine sand materials due to different thermal conductivity properties. A common misconception is that if you remove frost susceptible soils from a foundation that you have eliminated the potential of frost uplift, but in fact this is incorrect. If water can still enter the pores of the non-frost susceptible soils but cannot adequately drain, then the adfreeze pressure will be higher than that of a fine-grained soil which worsens the effect of frost uplift.

Constructability is, as it sounds, a measure of how easily a structure can be built, and with thousands of foundation elements, it's a key consideration in designing a cost-effective solution. Subsurface conditions can cause significant grief where construction is concerned, and broadly these are obstructions, groundwater and organic materials. Obstructions, typically in the form of cobbles, boulders, bedrock and buried refuse, are a deterrent to screw or driven pile foundations from reaching their target embedment depth.

Groundwater can create several construction challenges, including negatively impacting soil stability. Organic soil materials typically provide little resistance, with the likelihood of resistance decreasing as the organic content increases. Organic soils are often associated with the presence of saturated environments, which create further challenges related to overall soil resistance.

Survey methodology

The survey methodology must be selected based on the site-specific conditions, but that is often not known until the investigation work has started; the encountered conditions may necessitate a change in the proposed methodology at the start of the investigation, and how the process accommodates these changes can directly impact the quality of the collected information and overall reduction in risk.

The most common methodology is to start with boreholes, which includes soil sampling, whether that be of disturbed or undisturbed samples for classification and completion of subsequent laboratory testing and the completion of in-situ testing such as standard penetration tests, field vanes or the use of a cone penetrometer.

Since deep foundations are so commonly used for solar projects and can contain such a large number of foundation elements, understanding the potential for refusals, or the foundations' inability to reach the target embedment depth during construction, is important. Test pits are therefore also advisable. These allow for direct observation of excavated materials, whereas drilling methods require us to infer the presence of obstructions which can be less accurate.

Pre-production testing

The geotechnical investigation should provide a full understanding of the subsurface conditions and their corresponding geotechnical engineering properties, whether they are preliminary or final design parameters. You would also want to understand the potential variability of the subsurface conditions, and if a variation of the same foundation would be sufficient to ensure successful installation of the foundations or a completely different design should be considered.

Once the geotechnical investigation is completed, it is beneficial to complete a pre-production testing programme to optimise and verify design parameters and gain an understanding of any concerns that may arise during construction. The process involves field testing of a number of pile sizes and types in order to refine the design. Often this may need to be an iterative process that requires multiple phases to reach a final design. In many cases, this is not completed, and it can often directly impact the success of the foundation erection work and the overall risk associated with this activity.

Foundation types

There are four principal foundation types: driven piles, micropiles, helical piles and groundscrews. Each is profiled below, along with some insights into their pros and cons:

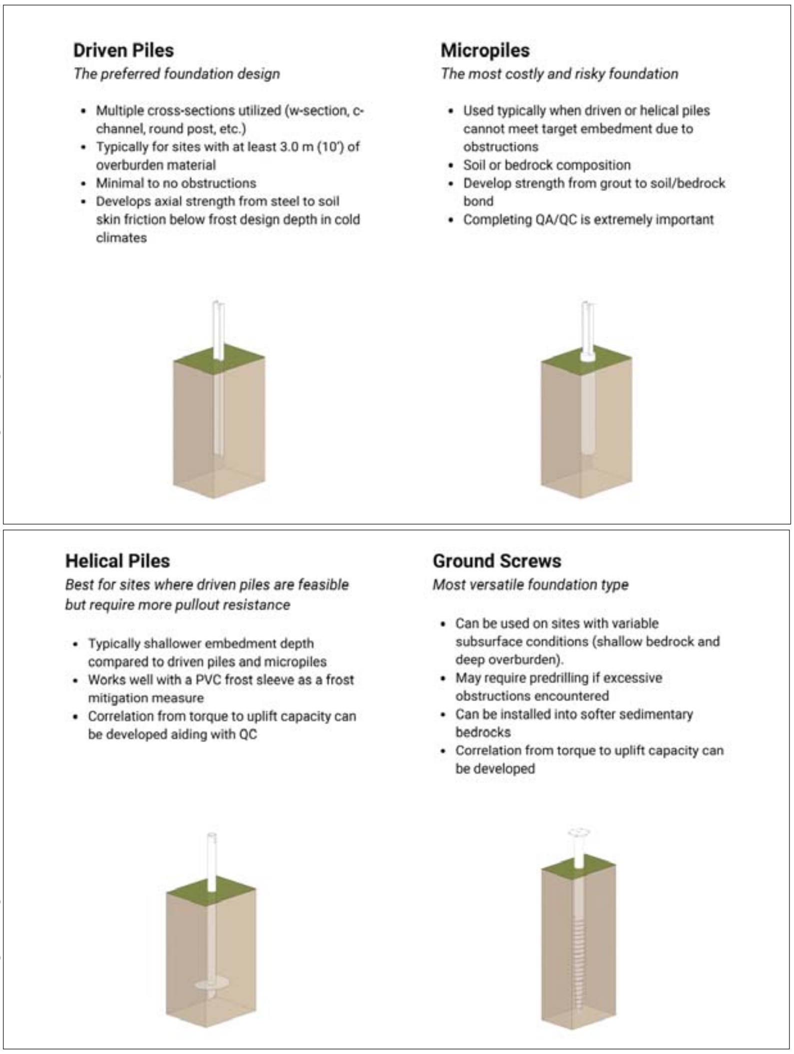
Driven piles: can come in a variety of different profiles, such as c-channels, w-sections or hollow structural sections. They should not be utilised in areas of shallow bedrock or in soils with excessive obstructions (typically cobbles and boulders), or very loose/soft soils. When shallow bedrock is encountered, consideration must be given to whether it is a softer bedrock (soft sedimentary bedrock or metamorphic) or a harder bedrock (hard sedimentary bedrock or igneous). If it's softer bedrock it may be feasible for a driven pile to penetrate the material, but this is only the case with very soft sedimentary bedrock such as sandstone or claystone; alternatives could be a predrilled hole with a groundscrew installed into it or utilising a micropile. With harder bedrocks, a micropile would be the preferred alternative.

Helical foundations: These typically have a single-blade orientation but may require more in very poor soils. They can be used in softer soils that will not develop adequate uplift resistance for a driven pile. Helical piles are quite often used in climatic regions that encounter extended periods below 0oC and therefore are subject to frost uplift loads which are typically higher than the wind uplift loads generated from the actual racking system. Typically, it is necessary to determine an approximate correlation between installation torque and uplift capacity. If this information is not interpreted by a qualified professional it could result in an underestimation of the uplift capacity. This often happens when minimal design investigation work has been completed or engineers with limited experience of these foundation types lead the design activities.

Groundscrews: These are typically used in very coarse materials, with large quantities of cobbles or boulders, and in soft bedrock environments. They cannot be used with very hard bedrock materials, unless you provide oversized predrill and then add aggregate back to this hole. This can result in a lot of effort to meet the quality control requirements and therefore is not a good solution as it may not yield favourable results and is costly. In a lot of conditions where this foundation is considered feasithe preferred design,

Credit: PRI Engineering

Credit: PRI Engineering



Different foundations systems are better suited to certain applications and conditions

Case study

Size: 6.4 MWDC

Location: US Virgin Islands

Customer: Polar Racking

Racking system: Core by Polar Racking (post storm)

Foundation: Groundscrew (pre-storm), driven round (post-storm)

Project Details:
The site had been previously destroyed by Hurricane Irma. PRI Engineering and BMR conducted an extensive site investigation and component testing programme to support the design of the racking structures and foundations. Previously, the facility had been supported by groundscrews, and little to no quality control had been completed during construction.

A driven round was utilised to penetrate dense overburden material and soft underlying bedrock.

The driven foundation utilised the in-situ strength of the soils instead of disturbing them as the groundscrews did.

New foundations were required on a system destroyed by Hurricane Irma, partly due to inadequate foundations

predrilling will be required. The predrilling diameter should ideally be no greater than the shaft of the groundcrew and ideally smaller so that you are not unnecessarily disturbing competent materials. If excessive amounts or shallow groundwater are encountered during predrilling, it's typical to encounter collapsing soils which will affect installation and meeting the design requirements, specifically torque which similar to a helical foundation can be utilised to estimate the uplift capacity.

Micropiles: These are used in similar conditions as a groundscrew, but when either a groundscrew cannot feasibly be installed due to subsurface conditions or materials are very loose. It is the highest cost option when compared to the others. This is primarily because anything made with concrete can be challenging as it is time-sensitive – meaning if it is on-site too long it may be deemed as non-useable; typically this is two hours from the time of batching unless specific admixtures are utilised which only increase the cost of the concrete. Also, these sites are quite often in remote areas and therefore the travel time to the sites could be high and once again because of the time-sensitive nature can be problematic. If being used in the most challenging places with groundwater issues and obstructions, micropiles will need to be installed using a continuous flight auger which will place the concrete (or grout) utilising an injection pump or other methods that place the material in a tremie fashion. This is to place the concrete/grout at the base of the boring so that it displaces the groundwater upwards as it is injected into the boring, this will ensure that the cement and aggregates do not segregate and ensure that it will cure as designed.

A fifth option is surface ballast, when penetration into subsurface is not feasible – one of the largest applications of this approach is over a landfill or when the underlying material is contaminated and cannot be penetrated. The surface ballasts are typically made of concrete but can also utilise earth or other geological materials. The surface geo-ballast is quite often used in remote areas when concrete or other specialised equipment may not be available, or if there is an abundance of geological waste material which can be economically used at the site.

Construction

During construction, a quality assurance/quality control programme should be completed to ensure that the foundations are being installed as per the design requirements and the anticipated subsurface conditions are being encountered. The subsurface environment can change dramatically throughout a single solar site. Preliminary desktop research and the pre-production testing efforts completed in advance, even the most thorough investigation, may not uncover all conditions that will be encountered during the construction process. While the clients and contractors will constantly mitigate equipment failures and disruptions, material supply, and most importantly, production rates on-site, these unknown site conditions can place severe strain on the site's efficiency and schedule.

Foundation design in the future

The solar racking foundation design is unique, as the physical structure is very lightweight and covers an extensive area. Traditionally, built structures have a very high dead weight and therefore the loading in the axial direction is primarily compressive. In the case of a solar racking system, most of the axial forces are in tension, which is due to either wind uplift acting on the racking system and then transferring these loads to the foundation system, or through frost uplift acting on the foundation and transferring these forces to the racking system and modules. Multiply that by the number of foundations over the vast area PV projects frequently cover, and it's clear there is a balance to strike between being conservative in the design because the risks are so high and our understanding of the interaction between frozen soils and foundations is limited, but also being aggressive with it because the number of foundation elements is so high that a small reduction in the foundation size or length could save millions.

Foundation design is a discipline that is sure to mature and develop in its sophistication. For example, in colder regions, our current understanding of the adfreeze process is only limited and needs improving for the determination of Adfreeze pressure. It is a very complex process and currently, there are only limited guidelines, which can result in a conservative design.

But what is certain is that, with the foundations for a solar project typically consuming around 7.5% of a project construction budget, getting it right is a critical element in maximising value. Understanding what lies beneath your project site is a vital step to derisking a project and ensuring it operates for as long and as profitably as expected. ■

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Solar PV and carbon border pricing mechanisms, an overview and assessment

Carbon pricing | The EU and US are leading efforts to reduce the carbon intensity of PV manufacturing through targeted import tariffs. As well as supporting decarbonisation efforts, such policies could also promote geographic diversification in the solar supply chain and greater supply resilience, writes Michael Parr of the Ultra Low Carbon Solar Alliance

Credit: Trina Solar

Policies to drive down the embodied carbon of solar hardware could have broader benefits

There has been growing attention over the last decade given to energy-intensive commodity industries such as steel, cement, glass and aluminum as global sources of carbon emissions. These industries are all significant carbon sources, and there have been a variety of efforts to reduce those emissions. These industries are also broadly distributed globally and are often located in areas of lower-cost electricity, which generally means areas with significant components of coal-fired power on the grid. Because of their broad distribution and the large number of individual producers, finding solutions to reduce the carbon emissions of these industries has required extensive collaboration that has often been led by industry or other private sector-organised approaches.

Solar manufacturing is also rapidly becoming a major source of carbon emissions and is beginning to receive attention as an energy-intensive commodity industry. Increasingly, countries are looking to price carbon as a means of reducing greenhouse gas emissions and are using the application of a carbon price on imports (sometimes referred to as a carbon border pricing mechanism, or CBAM) to ensure that imports are treated similarly to domestically manufactured goods.

This piece will begin with a short overview of the carbon emissions associated with solar manufacturing. It will then assess emerging carbon pricing mechanisms for commodity imports generally and will conclude with an examination of the potential effects of these mechanisms on the solar industry.

Solar manufacturing and carbon emissions

The production of metallurgical-grade silicon for use in solar cells involves a series of highly energy-intensive steps. These include refining raw silica to yield ultra-pure polysilicon, creating silicon ingots, and producing the silicon wafers that are the basis for solar cells. For example, the production of polysilicon by the Siemens method (the predominant technology in use) consumes in the order of 70-140 kilowatt-hours of electricity (kWh) per kilogram of product [1].

Industry analyst Johannes Bernreuter estimated the annual polysilicon production capacity of the top six producers (five of which are Chinese) at 470,000 metric tonnes (MT) in 2023 [2]. Across the industry, Thunder Said Energy estimated total polysilicon production capacity of some 700,000 MT in 2020, rising to 1,600,000 MT or 1.6 billion kilograms by 2023 (Figure 1) [3]. These production estimates suggest an annual energy consumption in 2023 of 112-224 billion kWh or an astounding 112,000-224,000 gigawatt hours for polysilicon manufacturing, the vast majority of it in China, which accounts for 90% of global production capacity [4]. While this is likely something of an overestimate, as not all of that manufacturing capacity will be in use at all times, it is indicative of the scale of energy use in the industry.

Because these energy-intensive elements of the solar industry are particularly concentrated in China, related carbon emissions are significant. According to Statista, the carbon intensity of electricity generation in China was 531.15 grams of carbon dioxide per kilowatt-hour (gCO_2/kWh) in 2022 [5]. The estimated 112,000-224,000 gigawatt hours of energy consumed to produce polysilicon in 2023, therefore, would have resulted in an estimated 60-120 million MT of CO2 emissions for this one segment of the supply chain for this one year. Even with

Source: Thunder Said Energy (2024)

Figure 1. Global polysilicon production capacity by company (2004-2023).

Source: Thunder Said Energy (2024)

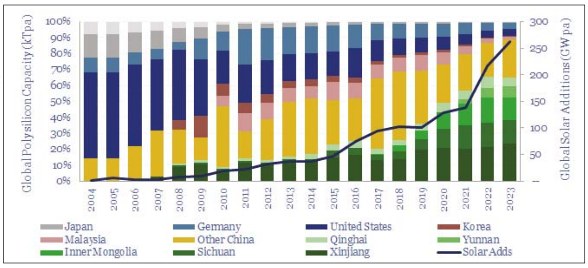

Figure 2. Polysilicon production by country Source: Thunder Said Energy (2024)

China's recent efforts to reduce the carbon intensity of its grid, these solar manufacturing-related carbon emissions are eye-opening, especially when considering they reflect only polysilicon production and do not capture carbon emissions from any other segment of the solar supply chain.

Indeed, the Clean Energy Buyers Institute has estimated that if projected growth in solar manufacturing to meet global PV demand growth continues to occur primarily in China, and if that production is not decarbonised, solar manufacturing could come to emit as much carbon as global aluminum manufacturing by 2030 and exceed it by 2040, with additional emissions in the order of 14-18 billion MT CO2 across the entire solar supply chain over the period 2020-2040 [6].

Currently, the lifecycle carbon emissions of a solar panel produced from a fully Chinese supply chain are roughly double those of a panel from a US or EU supply chain [7,8]. This has been a somewhat theoretical comparison until recently, due to the lack of meaningful capacity in certain elements of the solar supply chain outside of China, particularly silicon wafers. That is changing rapidly, though from a small base, as wafer production expands in Southeast Asia and as multiple producers look to begin wafer production at a multi-gigawatt scale in the US. We are also seeing wafering expand in Turkey.

There were several efforts aimed at expanding EU wafer capacity before excess inventory of solar panels in EU warehouses, cleared with fire-sale pricing, made virtually any EU solar manufacturing temporarily unprofitable and paused those efforts [9]. When the inventory glut is worked off, the market will stabilise and these EU wafer investments may proceed. There are also efforts to expand polysilicon production outside of China [10,11].

Carbon border adjustment mechanisms

Nations and companies that have worked to reduce their carbon intensity can find themselves competing against lower-cost products from countries and producers who have not similarly invested in decarbonisation. Thus, "leakage" of carbon emissions and industrial competitiveness from lower-emitting countries to higher-emitting countries with lower production costs is a significant concern for many elected and policy officials in the development of national or multinational carbon-reduction policies.

A variety of policy approaches to address these concerns have been bandied about. Various forms of import tariffs based on the difference in carbon intensity of an imported product and a like domestic product, intended to reduce the competitive disadvantage of decarbonising and the resultant shift of manufacturing to higher carbon producers by pricing carbon content, have emerged as the most popular policy response.

The EU's CBAM is such a programme. It has just begun its initial transitional, or pilot, phase, and the full programme will come into force as of 2026. It initially applies to cement, iron and steel, aluminum, fertilisers, electricity and hydrogen, with the intent to expand to other energy-intensive commodities as of 2030, which could include solar PV. In essence, importers will pay a fee for the embodied carbon in imports of these materials, with the carbon price determined by the price within the EU Emissions Trading Scheme (ETS), which is essentially the price that EU producers pay for their manufacturing carbon emissions; CBAM is being phased in as the free allocation of ETS allowances is being phased out. In essence, CBAM is intended to place a uniform cost on embodied carbon for both domestically produced and imported products.

Similar approaches have been broadly discussed in the US and are often the preferred option amongst large industries, as they minimise competitive distortions from domestic-only carbon pricing programmes and allow manufacturers to point to governmental action as the basis for price rises. Despite the somewhat fraught politics of climate and carbon emission limitations in the US, several pieces of legislation centred on CBAM-like policies are under discussion. The PROVE IT Act, a bipartisan bill that has been introduced in both the US Senate and House of Representatives, avoids the politics of carbon controls by simply requiring the US Department of Energy to calculate the differences in embodied carbon in domestically produced manufactured goods as compared to imports.

Covered products include aluminum and articles of aluminum, cement and articles of cement, iron and steel and articles of iron and steel, plastics and articles of plastic, biofuels, crude oil and refined petroleum products, fertiliser, glass, hydrogen, lithium-ion batteries, natural gas, petrochemicals, pulp and paper, refined strategic and critical minerals, including copper, cobalt, graphite, lithium, manganese, and nickel, solar cells and panels, uranium and wind turbines.

The PROVE IT Act is progressing through the legislative process; it was recently passed by the Senate Environment and Public Works Committee in a bipartisan vote with the broad support of the business community. The US business community is increasingly aware of their carbon advantage in manufacturing; having the US Government document the US carbon advantage for manufactured products is seen as a helpful tool to facilitate market preferences for lower carbon footprint products. This, for example, is why some major solar buyers in the US are interested in and employing the EPEAT ESG/low carbon ecolabel for PV as a criterion in their purchasing, as does the US government.

US Senator Cassidy (R-LA) has developed the Foreign Pollution Fee Act, which currently has two additional Republic cosponsors in the US Senate. The bill has the same scope of coverage as the PROVE IT Act and imposes a fee for the pollution intensity of imported products. As pollution is defined as greenhouse gas emissions in the bill, it is in essence a CBAM. The bill does not impose a corresponding carbon price on domestic manufacturers. The legislation has not yet received a hearing in Congress.

Senator Sheldon Whitehouse (D-RI), with additional Democratic cosponsors, has reintroduced his Clean Competition Act in the US Senate and a companion bill has been introduced in the US House of Representatives. The bill would, as of 2025, create a fee on excess carbon emissions in several industries including fossil fuels, refined petroleum products, petrochemicals, fertiliser, hydrogen, adipic acid, cement, iron and steel, aluminum, glass, pulp and paper, and ethanol. In 2027 coverage would be expanded to include additional imported finished goods, which might include solar PV. The fee would be based on the average carbon intensity of each of these US industrial sectors. It would apply to imports where the average carbon intensity of the sector in the producing country exceeded that of the US, as well as to US producers for their emissions that exceeded the US sector average. Three-quarters of the collected fees would fund a competitive grant programme for each of the covered industries that would support investments in the new technologies necessary to reduce their carbon footprints, and a quarter of the fees would be invested in decarbonisation efforts in developing nations. By placing a cost on carbon and then deploying the resulting revenues to help lower carbon emissions, the bill is intended to reduce emissions globally while ameliorating competitive disadvantages related to carbon intensity.

How each of these policy efforts will progress is uncertain, but their proliferation and, in the US, their bipartisan nature in an increasingly partisan political environment strongly suggest that we will see some form of carbon border adjustment mechanism in the major developed economies in the not-too-distant future. These discussions also come against the backdrop of growing US-China trade tensions, with indications that the EU and China may soon experience similar friction. They also come at a time of growing concerns about the strategic risks of the overconcentration of numerous supply chains in China, including clean energy materials and products, and a US and EU push for "reshoring" and "friendshoring" industrial production.

What does CBAM mean for solar?

Were any of these CBAM-type policies to come into effect and cover PV products, as seems likely, they could have significant impacts on the PV supply chain. At a minimum, such policies would serve to make solar products manufactured with lower carbon footprints more competitive in the nations with those policies, reflecting the relevant carbon price and their carbon intensity advantage. It would also send a powerful signal to the export-oriented Chinese PV industry that to remain competitive in the US and EU markets they would need to reduce the carbon intensity of their production. It would also provide motivation for those members of the rapidly developing Indian PV manufacturing sector who wish to serve Western markets to find ways to reduce their carbon intensity. Despite aggressive renewables deployment, the Indian grid is more carbon-intensive than the Chinese grid, where renewables deployment at scale has helped to reduce carbon intensity in the last decade. In private conversations with several Indian manufacturers, it is clear they recognise this sensitivity regarding embodied carbon; it will be interesting to see how decarbonisation develops in the Indian solar manufacturing sector.

The specifics of a CBAM policy, such as whether it looks at national grid level carbon intensity in the comparisons of industry sector averages or accounts for facility-specific factors, would likely influence whether the response would be more rapid national decarbonisation or efforts at decarbonisation just within the PV industry, such as by growing capacity in hydro-power rich areas and increasing self-power with renewables at PV production facilities.

Unlike traditional trade policies, which are often blunt instruments with unintended results and largely motivate efforts at tariff avoidance, a carbon metric is more transparent and objective and more difficult to "game". For example, we saw portions of the Chinese PV sector hopscotching from China to Taiwan to Southeast Asia in response to US tariffs, and producers in Southeast Asia are working to use just enough non-Chinese content to avoid the limits of the anti-dumping and countervailing duties the US has imposed on some imports from Southeast Asia. Carbon intensity metrics, particularly those that are grounded in public data such as national grid carbon intensity factors, are relatively straightforward to implement and motivate the more salutary behaviour of reducing carbon intensity.

Two potential effects of CBAM policies on solar manufacturing deserve particular attention. One is the expansion of the most energy-intensive components of the solar supply chain (polysilicon, ingots and wafers) in regions where power grids have lower levels of carbon intensity, such as hydropower-rich Brazil or Canada. As these are the supply chain components most heavily concentrated in China, such a shift would have positive effects on supply chain diversification and resilience. If CBAM policies motivated greater diversity in solar manufacturing locations, the overall effect would be fewer supply disruptions from logistical complications such as those experienced during Covid and currently, with shipping seeking to avoid conflict in the Red Sea. It could also cause significant reductions in the otherwise expected growth in solar manufacturing carbon emissions, making solar an even more important element of global emissions reductions. It should also be noted that as US-China geopolitical competition and tensions rise, so do the strategic risks of China limiting clean energy technology exports to certain nations as a political matter, which we are already seeing in numerous areas. A more globally diverse and resilient solar supply chain would reduce that strategic risk and bolster relationships with allied nations.

The second is that by helping to level the competitive playing field for PV products (by reducing the cost advantage of manufacturing in regions with low-cost but carbon-intensive power) through transparent and objective criteria, CBAM policies could reduce the demand for more traditional trade policy interventions such as anti-dumping tariffs, which can have more significant and unpredictable market-distorting effects. These trade measures are typically instigated by manufacturers who feel they are subject to unfair competition petitioning governments for trade policy interventions. If that competitive imbalance were relieved by CBAM fees, the motivation to seek traditional trade policy redress would decline.

CBAM policies, and the manufacturing shifts they would motivate, might result in somewhat higher manufacturing costs for some segments of the PV supply chain. However, technology advances continue to push PV manufacturing costs lower and module efficiency higher, and solar is sufficiently cost-competitive against other energy forms that nominal increases in some manufacturing costs associated with CBAM would be unlikely to have a material impact on global solar energy price competitiveness and deployment rates. We note that CBAM measures could also raise the cost of competing carbon-intensive forms of power generation, e.g. fuels, to the extent those are imported, further enhancing the cost advantage of PV. CBAM measures might also serve to increase political tensions between the US/EU and China, but if other trade actions were relaxed as CBAM levelled the solar playing field, the net difference in trade-related tensions could well be insignificant.

Summary

Solar manufacturing, particularly in China, where the majority of such manufacturing occurs, is carbon intensive, and there is growing awareness and concern about the carbon emissions associated with solar manufacturing. A carbon border adjustment mechanism is coming into force in the EU, and there are bipartisan efforts in the US Congress to develop similar measures. The US efforts specifically list solar manufacturing as a covered sector. The implementation of CBAM policy mechanisms would incentivise lower-carbon solar manufacturing and reduce the competitive advantage of solar manufacturing in high-carbon economies. The result would likely be reductions of PV manufacturing carbon intensity in China and perhaps India, as well as more manufacturing of the most energy-intensive elements of the solar supply chain (polysilicon, ingots and wafers) in lower carbon economies. It could also precipitate greater geographic diversification in the solar supply chain, leading to greater supply resilience. These shifts could result in incrementally higher manufacturing costs in some areas but would be unlikely to materially change the overall cost competitiveness of solar PV as compared with other forms of generation. The implementation of a more objective and transparent metric for trade in solar like a CBAM could well lessen the pressure for more traditional trade measures on solar goods and help to reduce uncertainty in the solar supply chain. ■

Turn to p.78 for further exploration of the impact of carbon pricing on module costs

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The costs to the solar industry of a price on carbon

Modules | Policies in the EU and US to impose a carbon price on imported materials and goods will inevitably hit solar manufacturers. Corrine Lin and Sherry Hsu assess where these costs will land and how the industry should be adapting in preparation

Solar imports into the EU and US face a price on embodied carbon

Credit: Rinson Chory, Unsplash

The EU's Carbon Border Adjustment Mechanism (CBAM) and the US' Clean Competition Act (CCA) have gradually come into the spotlight in the solar industry amid the world's increasing commitment to the low-carbon transition. Despite having had little impact thus far, some businesses are actively gearing up for the potential impact of the two policies.

CBAM: Heading towards new challenges

The CBAM regulation will enter into force on 1 January 2026, regulating the cement, steel and aluminium industries. Companies importing the covered goods will be required to pay a carbon price via CBAM, while the phasing-out of free allowances under the EU emissions trading scheme will take place in parallel. Although the EU's carbon tax does not cover the solar industry, the policy will still impact the industry in the long run. Figure 1 presents the CBAM carbon price trend until 2034, which is expected to come in at EUR160/tonne at the lowest under a conservative scenario. If factoring in the possibility of regulation becoming stricter, more industries being covered, and allowance-driven demand, carbon prices could hit EUR200/tonne at the highest. It's also worth noting that free allowances will be phased out completely in 2034, meaning that companies in the future will bear full responsibility for their emissions. Against this backdrop, it's critical for companies to manage carbon cost risks.

Although the full scope of CBAM regulation has yet to come into force, several companies have started optimising their manufacturing processes and improving the carbon efficiency of their products in response to potential requirements on solar products by CBAM. A new generation of low-carbon modules is on the rise, which with a higher efficiency and lower carbon footprint will not only comply with the new regulation, but also meet market demand for clean energy. Meanwhile, the implementation of CBAM will make carbon price fluctuation even more sensitive, thereby affecting the costs of solar products. Therefore, enhancing carbon risk management will ensure the competitiveness of companies.

Clean Competition Act: Welcoming advanced solar technology

While it remains uncertain the real impact of CCA, the US' policy direction for the low carbon transition is quite clear, meaning that the solar industry has to prepare for the impact. In contrast to CBAM, CCA provides a longer notice period and covers wider industries. Moreover, the US policy does not offer a free allowance, which will create more shocks to imports to the US in the early stage. Figure 2 shows the forecast for carbon tax from 2024 to 2030. The initial price is set at US$55 per metric ton of CO2 equivalent starting from 2025 and would increase at 5% above inflation per year. The calculation is based on the 2% inflation target of the Federal Reserve System, and it's expected that by 2030, carbon prices will reach US$80/tonne under a conservative scenario and may exceed US$90/tonne in the future.

To reduce carbon costs caused by emissions, it's more feasible and effective to invest more efforts in cutting carbon emissions from products. Some pioneering solar companies have invested in

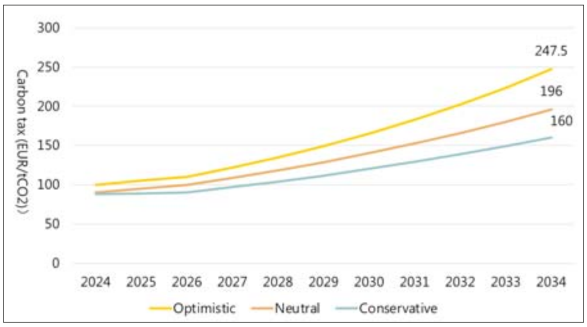

Figure 1. CBAM carbon price trends

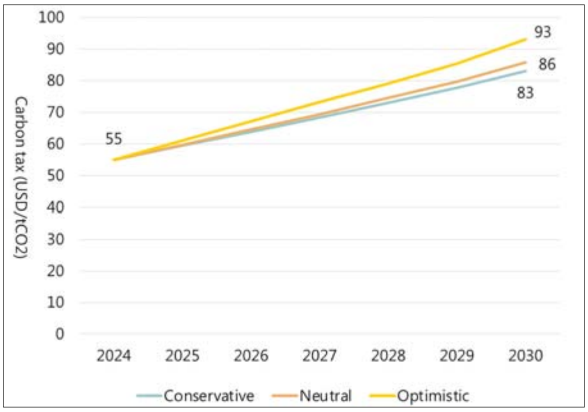

Figure 2. US carbon price trend

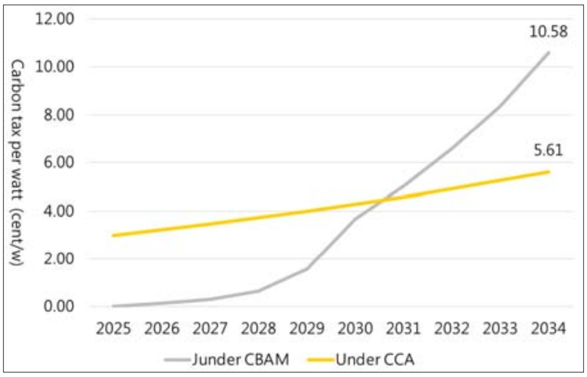

Figure 3. Additional costs per kilowatt under the carbon tax regimes

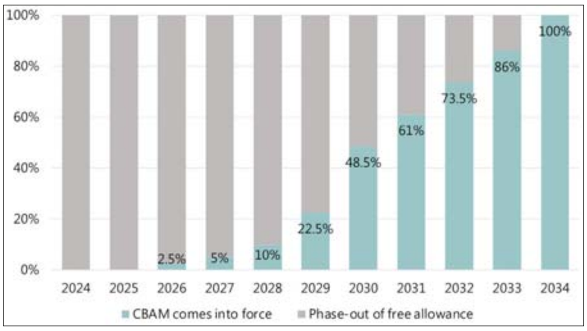

Figure 4. Timeline of CBAM and free allowance under EU ETS

technology R&D and production processes, such as higher efficiency cells, advanced manufacturing processes and environmentally friendly materials. Such technology upgrades not only help companies comply with regulations but also give them a more competitive edge to stand out in the market.

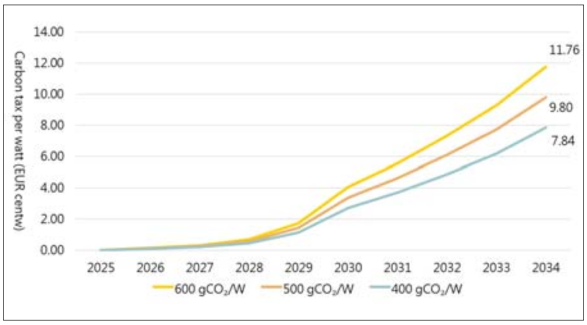

Figure 5. Additional cost per watt of modules with different carbon footprint under carbon tax regime

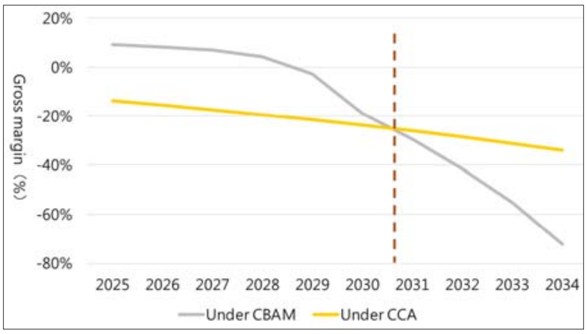

Figure 6. Product profitability under the carbon tax regime (on the premise of CCA coming into force in 2025)

Impact of CBAM and CCA on solar product costs and profits

From a policy-making perspective, CBAM and CCA are highly likely to have a direct impact on different products, meaning that the carbon tax will directly add production costs to products. Based on the carbon footprint statistics of modules from different countries, the current carbon footprint of products is around 500 kg of carbon dioxide per kilowatt, which is used as the index for the following calculation. Figure 3 presents the additional cost for each watt under the carbon tax regime and the calculating parameter includes a carbon tax that will increase annually, a free allowance that will decrease gradually, a policy that will become stricter and a gradual improvement in module efficiency. The figure shows that the impact of CBAM will manifest significantly from 2030 but before that, the impact of CCA is more profound, which brings an additional cost of US$0.04 per watt.

The reason why there's such a difference is that most climate targets are set for 2030, which is expected to see the EU making big adjustments to the policy by then, as more industries will be covered, carbon prices become higher and the free allowance cis ut by 26% (see Figure 4). As a result, it's expected that carbon tax will bring an additional cost per watt of US$0.10 by 2034. In the long term, module cost structures may consist of mainly carbon emissions instead of production costs.

Examining the impact of a carbon tax on different products, Figure 5 shows the cost changes under CBAM for modules with different carbon footprints (600g CO_2/W 500g CO_2/W; and 400g CO_2/W). It can be seen that the gap in carbon tax cost between modules with 400g CO_2/W and those with 600g may reach nearly €0.04/W by 2034, which means that products with lower carbon emissions receive less impact from the carbon tax, and thus low-carbon products will enjoy a significant advantage in the future.

Looking at product profitability, Figure 6 shows the impact of the carbon tax on modules' gross margin. The calculation here is based on the condition of fixed costs and prices. It can be seen that the impact of CCA will become pronounced from 2025, with carbon costs significantly affecting the gross margin of solar products. Businesses should prepare actively for the impact. Under the CBAM regulation, 2030 will become the cross-over point for the two, where the impact of CBAM on gross margin will surpass that of CCA significantly and widen with time. In light of this, manufacturers will be put in a dilemma between lowering costs or raising product prices in the future.

Looking ahead: Low-carbon solar era

As carbon policies across the globe have yet to have a direct impact on the solar industry, most solar companies have little experience in carbon management. However, carbon taxes, regardless of which mechanism, will impact the profitability of solar products in the coming years. Factoring in carbon emissions, carbon trade, or increasingly stricter policy, a carbon cost is inevitable. Solar companies should start planning for carbon management by making an inventory of their product lifecycle, including polysilicon, glass and aluminium frame materials, as well as their manufacturing process, transportation, usage, disposal and recycling to track the embedded carbon footprint and work towards producing low-carbon modules with less than 400g CO_2/W. The following are some of the most discussed issues in the industry currently:

1. Green factory design

The large profits of solar manufacturing and the rapid increase in solar installation in recent years resulted in the enormous growth of solar capacity between 2022 and 2024. China and Southeast Asia saw numerous new factories, while solar manufacturing started increasing in the US. Green factory design is one key element of green manufacturing. Manufacturers can factor in basic infrastructure including building, lighting and equipment, as well as the energy for powering the factory and environmental emissions in the early design stage of the factory. For instance, manufacturers can cut the carbon footprint of their products significantly in the future by using renewable energy for polysilicon and ingot-growing segments that take up a higher share of electricity consumption, or consider emissions factors when selecting factory sites.

Some are also exploring how to use renewable energy effectively by integrating energy storage and pairing it with micro-grid technology to make the whole manufacturing park low carbon. As the application of energy storage needs to factor in the existing energy system and the condition of energy usage, it will be more cost effective if manufacturers could consider these factors in the early design phase.

2 Re-examination of raw materials use
Currently, polysilicon accounts for more than 50% of the total emissions of mainstream bifacial modules, followed by glass at 10%. Since granular silicon produced using Fluidised Bed Reactor (FBR) technology performs better in terms of carbon footprint, leading FBR manufacturers have been ramping up capacity in recent years, driving up the market share of granular silicon during 2023 and 2024, from 5-10% to potentially hitting 15% this year. Manufacturers could reduce their carbon footprint further if they manage to increase the proportion of granular silicon in the ingot growing process in the future. The industry is also engaging in R&D in thinning glass and wafers.

The aluminium frame also accounts for higher emissions embedded in modules, sitting at around 8%. Manufacturers are also exploring other low-carbon materials for replacement, such as compound material frame technology.

3. Process optimisation
Wafer-thinning technology has advanced markedly as polysilicon prices skyrocketed in recent years. The mainstream thickness has been thinned down from p-type's 170µm to the current n-type's 130µm, making a significant contribution to carbon reduction. In addition, n-type TOPCon has replaced PERC in the second half of 2023 to become the next generation of mainstream cell technology; TOPCon's higher efficiency can also improve products' carbon emissions. In terms of low-carbon modules that have achieved mass production, most of which use low-temperature processes, theoretically HJT has greater potential for thinning wafers further in the future.

4. Product recycling
While solar recycling is in its infancy and has yet to form an industrial chain, the topic has been increasingly discussed since 2023 as the volume of waste modules has increased along with rapidly growing solar installations for over a decade. At present, the EU has formed a committee to assist members with dealing with waste modules. China and Southeast Asia, the manufacturing hubs, are expected to follow suit to increase the ratio of waste module recycling. Meanwhile, the industry needs to form professional recycling units for hazardous waste.

To gain competitiveness through low-carbon solar, manufacturers must also consider transportation as well as products with a lower proportion of embedded emissions since every ton of emissions would be reflected in costs in the era of carbon prices. Manufacturers must cut emissions in all aspects to optimise product effectiveness. ■

Authors

Corrine Lin is chief analyst at InfoLink Consulting. She has spent more than six years conducting in-depth research and analysis on the solar PV supply chain, technology trends, and capacity utilisation. She is also responsible for tracking prices across products and geographic markets. The weekly spot price she publishes on PV InfoLink website has become a key index for the solar industry.

Sherry Hsu is a researcher at Reccessary, a media platform focusing on renewable energy and carbon market information and trends in the Southeast Asia region. She focuses on product carbon footprint calculations, GHG emission regulations in various countries, and carbon emissions limits across industries to help businesses develop their carbon reduction strategies.

Inflation Reduction Act credit transferability attracting new investors in upstream and downstream markets

Finance | The first full year of the Inflation Reduction Act in the US has seen a flurry of transactions completed as solar developers and now manufacturers take advantage. Jonathan Tourino Jacobo looks at some of the emerging trends and future prospects in this lucrative new market

Credit: First Solar

Last year marked the first full year the Inflation Reduction Act (IRA) was in force, while the US Department of Treasury and the Internal Revenue Service (IRS) released several pieces of guidance during 2023 setting out how solar projects and PV manufacturing can make use of tax credit transferability freedoms set out in the legislation.

During the first part of the year, barely any transactions – for solar projects – were made, due to the draft guidance only being published in June. But a recent report from Crux – an ecosystem for developers, tax credit buyers, and financial institutions to transact and manage transferable tax credits – estimated that, with the key guidance now in the public domain, transaction volume in 2023 tax credits will roar to US$7-9 billion. This will lift total investment in clean energy tax attributes to US$30 billion, on top of an estimated US$23 billion in traditional tax equity.

"That is an enormous feat for a market that has been transactable for fewer than six months," the report said. "This isn't just good news for project developers trying to sell their credits, or corporate taxpayers who want to manage their tax liabilities. An efficient tax credit marketplace is a critical tool for driving new investment in the US economy."

A new player in town

The ability for solar projects to transfer tax credits, on top of the investment tax credit (ITC) or the production tax credit (PTC), will enable developers in the US the ability to sell all or a portion of the credits to third parties.

"We are seeing a slew of new participants in the tax credit market, many of which are large corporates, insurance companies, or bespoke brokerage services, because this creates another avenue for monetising these tax credits, and we are also seeing the existing players shift their models to accommodate for the changes," says Carl Fleming, a Washington DC-based partner at law firm McDermott Will & Emery.

Numbers for 2023 showed the increasing appetite for the tax credit market, and with guidance on Section 45X – which provides a credit for the domestic production and sale of certain eligible components such as cells, wafers and modules among others – published late in December, it is certainly going to attract more interest in the entire solar industry, both at upstream and downstream levels.

First Solar has been quick out of the blocks in taking advantage of the tax credit transfer freedoms offered to PV manufacturers under the IRA

"Now that the guidance [for Section 45X] is out, that tends to get investors off the sidelines," says Anne C. Loomis, a partner at law firm Troutman Pepper.

The appetite for clean energy credit transferability in 2024 is more than likely to increase not just in numbers but also in size, with the majority of respondents (67%) to Crux's survey expecting deal sizes to rise this year. Figures from Switzerland-headquartered financing entity Credit Suisse estimate investment in clean energy tax credits and other project tax attributes to reach US$83 billion by 2031.

Under the IRA, there is the baseline PTC and ITC as well as a new standalone ITC for storage. On top of this, however, one can stack on various adders (bonus credits) based on incentives for projects being built in certain areas, such as those with old coal mines, or using certain pieces of domestically sourced equipment. This "game changer" has opened a whole new environment, says Fleming. With this new playbook for optimising projects, developers are ultimately trying to capture as much additional value as possible from one project. The question of how to monetise these credits is key, and it's not just developers, but private equity and banks that are taking interest because it opens up new pools of people to do business with.

The IRA includes adders for clean energy projects developed in energy communities, which had previously relied heavily on fossil fuel production or may face challenges associated with the energy transition. Fleming says energy communities is an area where the legislation is already clear enough, with adequate certainty on whether a project meets the requirements.

One of the findings from Crux's report is that the attitude of buyers and sellers of tax credits in 2023 was differed considerably, with buyers more focused on risk. "They're more likely than either sellers or intermediaries to describe themselves as still 'learning about the market', and all of those who said they're not planning a transaction indicated that a clearer understanding of risk would help change that," says Crux.

Sellers, on the other hand, are evidently all in, with 93% saying they were planning to pursue a tax credit deal or already have. The biggest challenge for sellers is price transparency and knowing if they are getting the best price for their credits.

Another important aspect of Crux's report was the importance of intermediaries to help close the gap between buyers' and sellers' market expectations. "A common theme emerged throughout the research, and it bears repeating: over and over again we observed the importance of intermediaries (banks, brokers, tax advisors, technology platforms, and others) to build trust and transparency in this new market," the report said.

One positive aspect of these tax credits is that smaller deals have been made in 2023 when before the IRA smaller players might have not been able to realise tax benefits for their projects. "A large number of smaller deals — too small for a tax equity deal — took place in 2023. Many of these developers would not have been able to monetise their tax benefits pre-IRA," explains Crux. The majority of the transactions (80%) – this includes all technologies and not just solar PV – for which the company received data were credit sales of US$50 million or less.

"2023 was also a unique year — most large wind and solar projects with credits to sell in 2023 received committed funding from tax equity partners before the year began and may not have had credits to sell," explains Crux.

The average deal size, based on ITC, on Crux's dataset for solar PV was US$18.32 million – including commercial and industrial (C&I) – or US$50 million for utility-scale projects only, whereas the average credit price reached 90.7 cents per dollar – including C&I – and 92 cents per dollar for utility-scale solar only.

Manufacturing boon

This is not just the case for the downstream part of the solar industry as the upstream will also be able to take advantage of tax credit transferability. A case in point is thin-film module manufacturer First Solar. At the end of 2023, the Arizona-based company entered into two separate tax credit transfer agreements (TCTAs) to sell US$500 million and up to US$200 million of advanced manufacturing production tax credits to finance tech company Fiserv. This was only days after the US Department of Treasury and the IRS released a proposed guidance on Section 45X credits on advanced manufacturing production credits.

First Solar's transferability deal is one of several options for the solar manufacturing industry to consider, says Troutman Pepper's Loomis, as they could also opt for a typical construction loan with the idea they will pay off the loan with the direct payment under 45X, once they have received it from the US government. "That will be a combination of traditional debt, and then tax credit via the direct payment," she says.

Another possibility that might arise in the coming months and years is for a solar manufacturer to sign a tax equity partnership around the ownership of a facility that produces products – from polysilicon to modules and other solar components – which earn the 45X credit, adds Loomis.

One of the key advantages of First Solar securing a deal so early is that the company already has production going in the US. "They have some manufacturing that generated actual tax credits in 2023. They've got credit they can sell right now. Whereas a new manufacturer trying to establish a factory, they don't have anything yet produced and sold. They're probably going to need to take on that debt in order to get their facility in place," explains Loomis.

Furthermore, the fact that First Solar is more vertically integrated than most of the solar manufacturers that have announced new or increased capacity so far allowed the company to stack on different 45X credits, adds Loomis. "They're getting a little more bang for their buck when they sell the product in terms of the tax credit."

One issue highlighted last year by the advisory body Clean Energy Associates (CEA) in a blog post on *PV Tech* was the looming imbalance between module capacity announced and the rest of the upstream supply chain. Indeed, only a few companies have so far announced capacity for at least modules and cell capacity to be built in the US, with Korean-owned solar PV manufacturer Qcells among the few to build from ingots to modules.

With the guidance now published and being "straightforward", Loomis expects it will make manufacturers more comfortable that "they're going to be able to generate incentives under the IRA in a certain amount".

If First Solar was the kickstart for the solar manufacturing industry to sign deals around 45X, this year and 2025 are expected to see more similar ones, though not for the same amount due to the reasons mentioned above – capacity already in production and more vertically integrated than most companies in the US.

Finally, the 45X credit guidance released last December will give a much-needed boost to the solar manufacturing industry in the US to build domestic capacity. Not only that but as plants become operational, developers will also benefit from it thanks to the adder for domestic content – which would give access to a 10% bonus ITC.

However, if the upcoming disparity between module capacity versus cell capacity continues and manufacturers still have to rely on imported solar cells, this might make it much more complicated for a solar project to get access to that extra 10%.

The biggest challenge at present is navigating the complexity of the inputs in the IRA, Fleming says, adding: "It's a challenge and an opportunity because this is so complex and so lucrative. It presents an opportunity to rethink almost every developer's business model." ■

Additional reporting by Tom Kenning

Presented to you by: Energy Storage NEWS

STORAGE & SMART POWER

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Introduction

Welcome to another edition of 'Storage & Smart Power', brought to you by *Energy-Storage.news*.

Across the pages that follow, you'll find our usual variety of feature and technical aticles, focused on the topics, technologies and trends impacting the energy storage industry that our readers should know about.

As one of our guest contributors points out, the industry may well have doubled in megawatt-hour terms during 2023 and the growth is highly likely to continue this year. So, we hope that from this first quarter edition of the journal to the last, we can provide a useful backdrop to the events that shape it.

That said, there are nuances to that growth: the UK market, Europe's large-scale battery storage market leader by some way, is experiencing a period of low revenues, for example, and we all await with bated breath the outcomes of elections taking place in roughly half of all the world's democratic nations in 2024.

In this edition you can read about:

BESS pricing: We're excited to bring you a deep-dive into battery storage pricing, authored by Dan Shreve at Clean Energy Associates (CEA). Likely to be a recurring theme for decades to come, Shreve notes that falls in raw material prices are highly welcome but are far from the only factor that the industry should be thinking about.

Looking ahead: Sweta Sundaram, director of BESS project design at RWE Clean Energy, offers a retrospective on the past couple of years of the market's evolution and considers what we need to think about going forward.

Year in Review: As a complement to that piece, we bring you some highlights from our Year in Review series from the site, canvassing opinion from many of the industry's leading lights including developers, system integrators and EPC providers.

Case study: Italy's BESS market has been identified by many as one of the main ones to watch in Europe this coming year. A team from Benny Energia has authored this fascinating technical case study into what it takes to design one of the biggest projects in development there.

Also worth noting is that the growth of maturing markets is being complemented by increasing activity in emerging markets. Perhaps nowhere is this better evidenced than the rise of the Energy Storage Summit series of conferences.

The Summits held in London and Texas for the European and US markets are now approaching the end of their first decade, which is amazing to see. Solar Media's industry-leading events team now also have Energy Storage Summits in Asia, Latin America and Central and Eastern Europe in the portfolio.

For the first time this year, the team will also be going to Sydney to host the inaugural Energy Storage Summit Australia (19-20 May). The level of interest from attendees and speakers has been excellent already and we're really looking forward to seeing many of you there.

Andy Colthorpe
Editor
Energy-Storage.news @ Solar Media

BloombergNEF launches Tier 1 list of BESS providers

BloombergNEF (BNEF) has launched its Energy Storage Tier 1 list of providers, noting growth in new players from the China market. The Tier 1 ranking of battery energy storage system (BESS) providers was released earlier his month. While its names have not been disclosed publicly, Energy-Storage.news can reveal that Fluence, Tesla, Powin, Wärtsilä and Hithium are there. One notable new entrant is China-based Kehua (Xiamen Kehua Digital Energy Tech), primarily a power conversion specialist but increasingly in the BESS market. Another notable inclusion is vanadium redox flow battery (VRFB) provider Invinity Energy Systems, most likely the only non-lithium manufacturer on the list.

Credit: Invinity Energy Systems

Flow battery maker Invinity Energy Systems features on the BloombergNEF Tier 1 BESS provider list

LFP price falls 'make first life batteries more attractive' than second life ones

The increasing cost-competitiveness of LFP battery cells has made first life batteries more attractive than second life ones, Finland-based BESS solutions firm Cactos told Energy-Storage.news after a €26 million (US$28.5 million) fundraise. When the firm raised €2.5 million back in November 2022, it presented itself as primarily repurposing used batteries from Tesla electric vehicles (EVs) into stationary BESS, otherwise known as second life energy storage. However, founder and CEO Oskari Jaakkola said in January that falls in the prices of new lithium iron phosphate (LFP) batteries have since changed this.

California solar-plus-storage project with world's largest BESS fully online

Edwards & Sanborn solar-plus-storage project in California is now fully online, with 875MWdc of solar PV and 3,287MWh of battery energy storage system (BESS) capacity, the world's largest. The 4,600-acre project in Kern County comprises 1.9 million PV modules from First Solar and BESS units from LG Chem, Samsung and BYD totalling 3,287MWh of energy storage capacity. That makes it bigger than the current largest BESS in the world, Vistra's 750MW/3,000MWh facility at Moss Landing, also in California, which also came online in two phases. Mortenson said in late January that it has reached 'substantial completion' and is 'fully online'.

Gotion's first 'Made in USA' ESS battery packs roll off Silicon Valley production line

China-headquartered lithium-ion battery maker Gotion High-Tech has produced the first battery pack at its new factory in California's Silicon Valley. The first pack came off the production line. The factory is dedicated to portable and residential energy storage system products ranging from 3kWh to 30kWh. It has a planned 1GWh annual production capacity when fully ramped. While it therefore represents a fairly small production plant and won't be producing cells, for Gotion it marks a first step in a 'Made in USA' production strategy. It is also an early addition to the US' relatively small base of factories dedicated to stationary storage.

UK proposes support mechanism for long-duration energy storage

The UK government launched its consultation on its proposals for kickstarting investment into long-duration energy storage (LDES), which includes a cap-and-floor mechanism and excludes lithium-ion from being eligible. LDES will be pivotal in delivering a smart and flexible energy system integrating low-carbon power, heat and transport. The consultation outline said 20GW of LDES deployments between 2030 and 2050 could result in system savings of £24 billion (US$30.5 billion). LCP Delta and Regen provided the analysis for the Department for Energy Security and Net Zero's (DESNZ) 'Long duration electricity storage consultation', published 9 January and open for comment until 5 March 2024.

Calpine Corporation closes US$1 billion financing for 680MW California BESS

Gas and geothermal plant developer and operator Calpine Corporation closed syndicated financing for what could be one of the largest BESS projects in the US. The credit facilities totalling over US$1 billion will finance the development and construction of a 680MW BESS project in Menifee, Riverside County, California, law firm and advisor to Calpine on the financing White & Case said in mid-January). It will be built in five phases with construction already underway, Calpine announced in December 2023 calling the project the 680MW 'Nova BESS'. When completed it will be one of the largest BESS assets in the US.

Victoria's SEC, Equis Australia get AU$400 million for NEM's first four-hour battery storage project

Equis Australia and the State Electricity Commission (SEC) for Victoria have secured AU$400 million (US$260.88 million) for their Melbourne Renewable Energy Hub (MREH) battery storage project, comprising three BESS assets with a total output of 600MW and capacity of 1.6GWh. Expected total cost of the project is AU$1 billion including AU$249 million committed by the SEC, a state-owned entity set up last year by the Victorian government to direct investment into 4.5GW of renewables and storage. Claimed as the largest debt financing package to date for a grid-scale BESS project in Australia, it is the first financial close of a four-hour duration BESS connecting to the National Electricity Market (NEM).

What goes up must come down: A review of battery energy storage system pricing

Pricing | Despite geopolitical unrest, the global energy storage system market doubled in 2023 by gigawatt-hours installed. Dan Shreve of Clean Energy Associates looks at the pricing dynamics helping propel storage to ever greater heights


The Crimson BESS project in California, the largest that was commissioned in 2022 anywhere in the world at 350MW/1,400MWh

Credit: Axium Infrastructure/Canadian Solar Inc

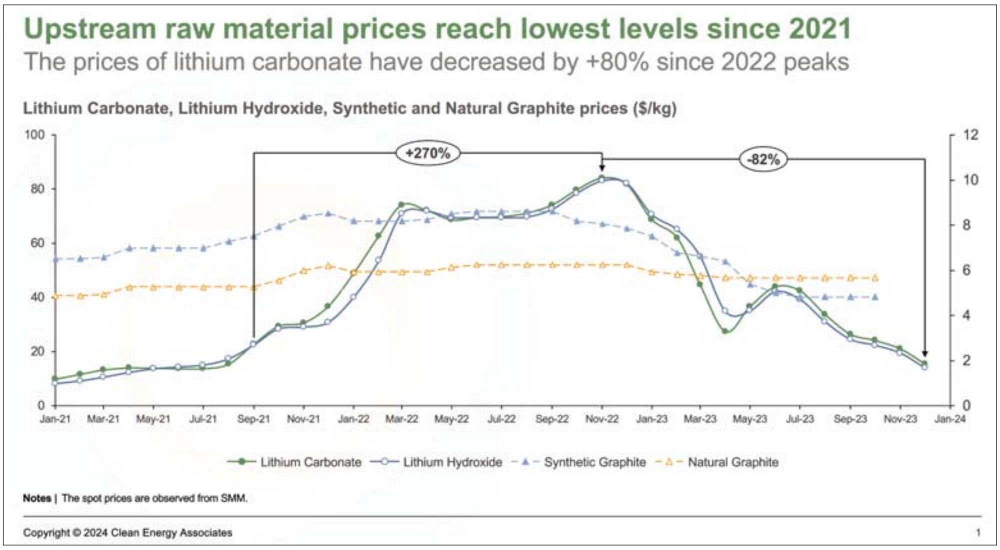
2023 is in the books, and early indications are that the global energy storage system (ESS) market may very well have doubled again in terms of gigawatt-hours (GWh) installed. This is a remarkable feat, especially in the face of geopolitical tumult, elevated interest rates and impossibly crowded interconnection queues. The market has shown reliance and is, indeed, poised for further growth, with a fourfold increase in annual installs possible by 2030. The reason why is simple: pricing.

As a start, CEA has found that pricing for an ESS direct current (DC) container — comprised of lithium iron phosphate (LFP) cells, 20ft, ~3.7MWh capacity, delivered with duties paid to the US from China — fell from peaks of US$270/kWh in mid-2022 to US$180/kWh by the end of 2023.

The primary price driver is universally recognised as a frothy lithium market that suddenly lost its fizz. Lithium carbonate pricing is down more than 80% from its 2022 peak. Supply/demand imbalances are to blame; or rather, how third-party estimates regarding those imbalances developed over the past three years (Figure 1).

To illustrate, in December 2021, S&P Global forecasted 2023 global lithium supply to top 762,000 tons, with a small surplus of 9,000 tons over demand. By the end of 2022, supply estimates for 2023 had grown to 864,000 tons, surpluses were nil and long-term shortages were expected. The market shifted dramatically in 2023, and S&P's latest estimate pegged global lithium supply at 968,000 tons, corresponding to a market surplus of 95,000 tons. A longer-term lithium carbonate surplus is now the industry consensus.

To be clear, the supply swing caught the entire market by surprise. Most industry pundits misjudged the pace of supply expansion from existing lithium mines, the dwindling electric vehicle (EV) demand dynamics, and the apprehensive buying behaviour in this still-youthful commodity segment.



Source: CEA

Figure 1. Upstream raw material prices since 2021

For example, although supply/demand imbalances drove price volatility from 2021 through 2023, the magnitude of those price excursions was exacerbated by stocking and destocking within the lithium-ion battery value chain. EV battery cell suppliers, especially those in China, have been locked in a heated battle for market share for years. Fears of critical raw material shortages at a time when global EV demand was achieving growth rates of +60% stoked irrational buying behaviour.

The result was a 270% increase in lithium carbonate costs from Q3 2021 to Q4 2022. The removal of China's New Energy Vehicle incentive in 2023, lingering range anxieties among Western consumers and a global increase in interest rates cast a pall on the EV market, resulting in a "disappointing" YOY growth rate of 31%. As demand slipped, suppliers were left sitting atop mountains of inventory and thus moved aggressively on price to bring their balance sheets back in order.

Savvy ESS developers recognise the critical importance of monitoring the broader EV sector alongside their own market. EVs represent around 80% of global lithium-ion battery demand, and the knock-on impacts to the ESS segment in terms of raw material pricing are meaningful as DC container suppliers generally apply raw material index pricing to their proposals.

Consequently, ESS developers and integrators should be mindful of near- to mid-term EV downside demand risk as they could be leaving money on the table. The next wave of EV adopters will need a rollback of interest rates, rollout of lower-cost EVs and an expansion of charging infrastructure, all of which will take time. BNEF just downgraded its global EV forecast (again) for 2024 by 775,000 vehicles.

Just when you thought it was safe… pricing falls to new lows

ESS market participants entered 2024 with enthusiasm and confidence, under the impression that market conditions had settled down and that they would finally be able to ink purchase orders. That euphoria was dashed by the time Intersolar North America 2024 took place as US$20/kg lithium carbonate pricing fell to US$14/kg. This left many to wonder where the floor for lithium really is. Interviews with ESS developers by CEA at the event revealed pricing for DC containers had dropped again, with average pricing at US$150/kWh. Aggressive bids from Tier II/III suppliers seeking to gain a foothold in the US were even lower, which raises the question as to whether current pricing is sustainable.

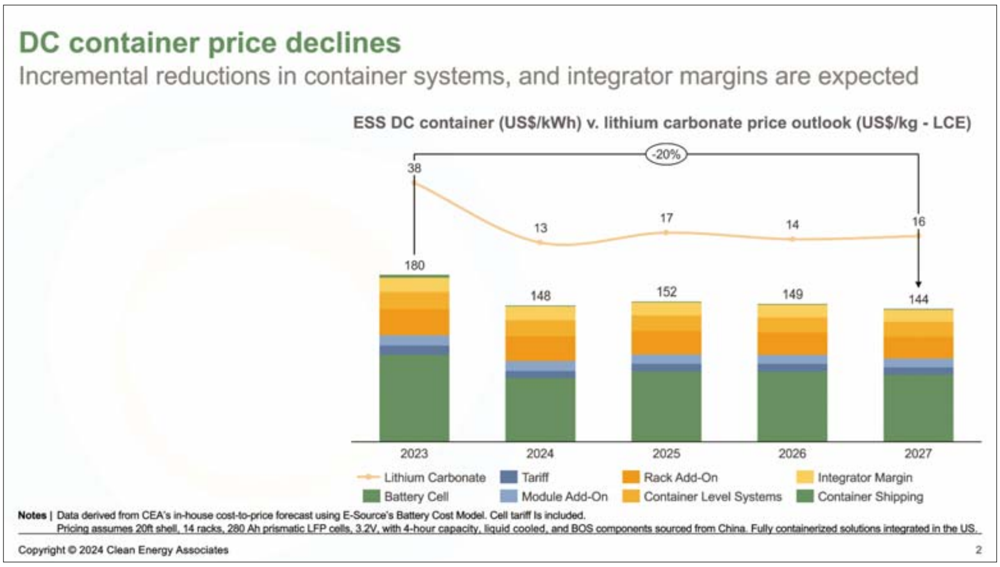


Figure 2. DC container pricing, 2023-27

Lithium's impact on ESS system pricing has been established but does not fully explain the extent of current market pricing. In fact, the lithium impact is diminishing mightily, as lithium carbonate within the battery cathode constitutes only around 5% of DC container system cost at current market pricing. CEA has been advocating for months that ESS developers and integrators begin to evaluate other price drivers for their DC container buy, including the impact of anode active materials costs, increased battery module manufacturing efficiencies, battery cell technology advancements and supplier margins in general.

Anode active materials (AAM) costs, most notably synthetic graphite, have been in the spotlight lately because of China's export regulations pertaining to that material. Concerns regarding an outright ban on graphite exports proved to be ill-placed, however, as Chinese officials have already provided export licences to chemical providers outside of China such as South Korea's Posco. Pricing impacts were also negligible as more than 90% of AAM production resides in China, where capacity remains grossly oversupplied. In fact, pricing has the potential to push lower as AAM producers introduce lower-cost feedstocks such as higher-sulfur petroleum coke versus needle coke from coal.

In terms of production efficiencies, the market continues to move along the same path as the solar photovoltaic market, pushing to increase the level of automation applied at gigafactories. In the case of batteries, operational scale has enabled producers to introduce automation to handle tasks such as cell sorting, cell stacking, busbar installation and welding of electrical connections. Battery module balance of system component integration and cell/module testing likewise are being automated to increase production throughput. These capital investments have a meaningful impact and can lower DC container production costs by more than US$10/kWh.

Similarly, supplier value chain integration investment is continuing in an effort to reduce margin stacking. Client-facing system integrators must do their utmost to gain control over as much of their bill of materials as possible. Companies with end-to-end supply capability are already well-positioned. And third-party integrators able to qualify multiple battery cell vendors can also be quite competitive if they can attain sufficient scale to manufacture their own battery racks. Module assembly automation may be more challenging for integrators looking to gain buying power by diversifying their cell supply, as different cell types could complicate production processes.

Technology advancement in the ESS sector will also contribute to a steady downward price trajectory for DC battery containers. The ESS value chain remains focused on evolutionary advancements to the ubiquitous prismatic LFP battery cell, as evidenced by the mass market transition from 280Ah to +300Ah battery cells. This is largely the result of battery manufacturers increasing electrode active material loading while reducing electrode thickness, without sacrificing battery performance. This evolution in energy density will yield incremental cost reductions from the current 280Ah architecture in large part thanks to balance of system savings at the container level.

Pricing paranoia sets in…

Pricing paranoia is beginning to set in as procurement professionals shrug off the good news regarding price declines and instead debate the probability of a battery container pricing rebound, when it may occur and to what extent. Their concern is a valid one, especially given the price volatility the ESS market has experienced since the COVID-19 pandemic. Nevertheless, most market indicators point toward

> "Despite the roller coaster ride of the past 24 months, the likelihood that lithium markets fall into a structural supply deficit is unlikely. Lithium exploration and extraction ventures continue to make headlines, with new reserves being proven across North America, Western Australia and South America"

a period of relative tranquility, although geopolitics can upset the apple cart.

For starters, despite the roller coaster ride of the past 24 months, the likelihood that lithium markets fall into a structural supply deficit is unlikely. Lithium exploration and extraction ventures continue to make headlines, with new reserves being proven across North America, Western Australia and South America. Oil and gas giants are entering the space with new technologies such as Direct Lithium Extraction.

Risks remain, especially given the mass of junior miners that entered the sector when prices topped out at US$80/kg lithium carbonate equivalent. However, underfunded ventures with strong natural resource claims will be quickly snapped up by established mining conglomerates seeking to expand their global footprint.

On the demand side, a dramatic increase in EV adoption seems unlikely without a correspondingly dramatic increase in charging infrastructure deployment. The 2021 Infrastructure Investment and Jobs Act (IIJA) already earmarked $7.5 billion in funding for electric vehicle charging infrastructure, so additional funding is unlikely to move the EV adoption needle. Similarly, ESS is poised for tremendous growth, but in major markets like the U.S., permitting and clogged interconnection queues limit growth trajectories, not funding. Thus, as far as upstream supply/demand dynamics are concerned, imbalances are likely to be short-lived and impart a lesser impact to global lithium prices.

The ESS downstream supply chain continues to expand, and with it the sophistication of production processes and quality of Tier I/II manufacturers. Consequently, as with other renewable energy technologies, the story is one of continued cost reduction, as battery cell manufacturers make incremental tweaks to cathode (lithium iron phosphate to lithium manganese iron phosphate) and anode (graphite silicon) chemistries to further increase energy density and lower DC container costs. Margins are also likely to be held in check, as gross oversupply at a global level already is in place. And with no signs of the pace of investment slowing, the situation will only get worse. ESS pricing dynamics are ebbing ever closer to PV pricing dynamics.

It's Super Bowl season… time to toss the political football

When ranking relative risks to battery pricing and project profitability, CEA handicappers offer the following as the most likely drivers:

1. US trade policy
2. US general elections

CEA's top concern in terms of resource availability and pricing is the expansion of the Uyghur Forced Labor Prevention Act (UFLPA) into the ESS sector. UFLPA enforcement upended the US solar market in 2022 and would create an even larger disruption to the ESS market given the exceptionally complicated supply chains supporting DC container production. Unravelling the origins of critical raw materials flowing through those supply chains to the satisfaction of US Customs and Border Protection (CBP), officials would take months or maybe longer.

Forward-looking developers and manufacturers are beginning to work through traceability programmes in advance of any government action. Nevertheless, substantial battery or DC container detainments under UFLPA would immediately create supply/demand imbalances both in the US and abroad. This would result in a substantial price premium for battery vendors able to deliver a CBP-compliant solution. As a reference, pricing for UFLPA and Antidumping and Countervailing Duties compliant PV modules with existing US import tariffs from Southeast Asia is 10% higher than global pricing for Chinese-made modules.

The IRA is not bulletproof

The Inflation Reduction Act (IRA) is central to current US energy transition plans, and any changes to its structure or the value of its incentive mechanisms could have detrimental impacts to both the domestic ESS and EV sectors. A new administration could hinder its implementation through executive action by withholding loans and grants, or even revising Department of Treasury guidance for rules that have not been finalised. A new Congress could potentially revisit the Investment Tax Credit, Production Tax Credit or the New Clean Vehicle Credit.

A repeal of these provisions would affect pricing and demand for battery cells, modules and DC containers in the US. ■

Author

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Li-ion BESS: Look-back and lessons for the future

The Edwards Sanborn solar and storage project in Kern County, California, features the largest BESS in the world at the time of writing, at 3,287MWh

Credit: Terra-Gen/Mortenson

Lithium-ion | Two years of volatility in the lithium-ion battery storage industry have seen prices tumble and a host of supply-chain complexities come to the fore. As Swetha Sundaram of RWE Clean Energy writes, the winners in this fast-changing market will be those who are best prepared

The last couple of years have been a strange time for the world, with wild ups and downs impacting several industries differently. The lithium-ion-based battery energy storage industry is no exception – swung by the push and pull of supply chain dynamics and key policy developments in the US. The stationary BESS industry has been reactive in most aspects, reeling to control project economics and schedules. But the industry as a whole has learned several lessons and proactive measures to implement.

Price swings like never before

Lithium mineral prices, specifically lithium carbonate, a key component for lithium-ion batteries, have experienced quite a roller-coaster in the past few years. The prices surged in the second half of 2022 as high as 10x of average historical levels. This trend was rooted in the overall shift and positive sentiment around transportation electrification, especially electric vehicles (EVs) around the world. Lithium supply at the time was not able to scale to meet this demand at such a rapid pace – depending on the process of mining and extraction, it can take three to five years to bring new capacity online because of the permitting and capital-intensive nature of extraction.

However, due to a combination of market factors, namely anticipated reduction of EV purchases in China because of the anticipated expiry of government subsidies, the lack of EVs as forecasted because of COVID-induced limited mobility and a big wave of new factories expected to flood the supply-side, prices came back down in dramatic fashion in 2023 compared to highs in November 2022.

As a result of these market dynamics, two noteworthy things ensued: lithium-ion battery suppliers began indexing the price of batteries to raw materials (RMI)

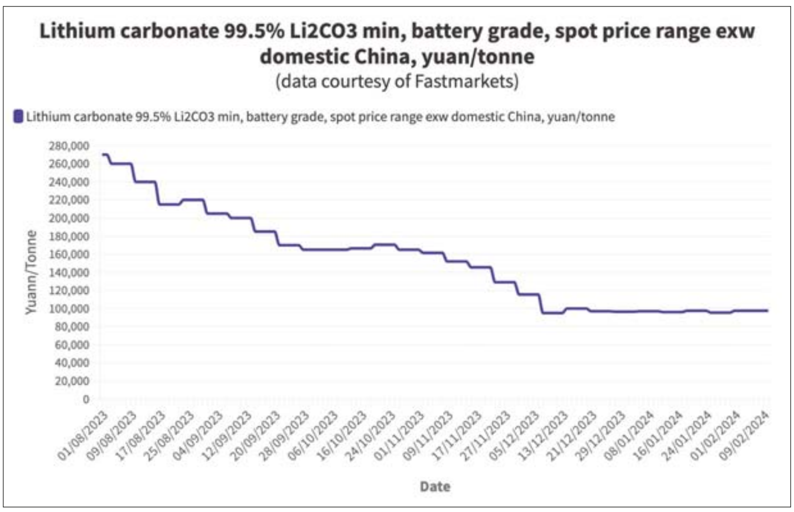

Figure 1. Lithium carbonate prices Aug 2023 to February 2024

Source: Fastmarkets

such as lithium carbonate to mitigate their risk exposure; and the system cost of building BESS increased compared to prior years. While time will tell if RMI pricing will be here to stay as standard practice, BESS costs stabilised in H2 2023, and continue on their anticipated downward trend from 2024. (For more insights into BESS pricing, turn to p.90 for Clean Energy Associates' analyses of recent trends.)

Supply-chain plagues other components

Key balance-of-plant (BOP) equipment needed for BESS systems – such as transformers, MV switchgears, enclosures and steel – have been plagued by supply-chain issues leading to unprecedented lead times. As of December 2023, owners and EPCs are facing up to two to three-year lead times for main power transformers when the historical norm has been about one year. Orders for auxiliary transformers needed to supply auxiliary power to BESS containers need to be placed at least six months to one year in advance. High-voltage breakers are worse, with some suppliers asking for up to a five-year lead time for production slots. This change is mainly attributed to labour shortages and supply-chain issues stemming from the COVID period. Volatile commodity markets for copper, aluminium and steel, coupled with workforce gaps and retention issues, impede the expansion of production. Further, the demand for such equipment is growing fast from developers with plans to build huge renewable projects in great volume, as well as from utilities to perform network upgrades to integrate more renewables. Utility off-takers are often valuing BESS projects that can come online earlier higher than later ones, creating a race to achieve aggressive commercial operation dates (CODs) and further fuelling the demand for equipment with expedited delivery.

Temporary wrinkle in BESS market

These factors have collectively caused a wrinkle in planning metrics for developers of utility-scale BESS projects and rolling delays in CODs of projects under execution. CODs sometimes need to be dictated by equipment that has much longer lead times than planned. EPC firms need to be engaged at least 18 months before the start of construction so that design can be progressed and appropriate equipment orders placed in time. Finally, interconnection-related delays are also being experienced because of long lead times for equipment required for upgrades when connecting into a utility's substation – at a time when interconnection queues are extremely backlogged with projects in most regions. As a result of these hurdles, utility-scale BESS project deployments slowed in the beginning of 2023 compared to prior years.

Market correction

Entering 2024, the BESS industry has already bounced back on track with bullish projections. 2023 deployment volume is expected to dwarf that seen in 2022, absorbing delays from the first half. On a short-term scale, this is attributed to battery pricing falling back to expected trajectories. At a macro level, the major contributing factor has been the IRA and a growing understanding of its provisions. Interconnection process updates, spurred by FERC Order 23, aim to streamline inefficient interconnection processes for BESS and other generation resources and provide more certainty to project schedules. The set measures to intake projects as clusters for faster processing, requiring study timelines to be established and requiring larger deposits from developers for projects to be in the queue, are all expected to streamline queues and make projects more guaranteed and economical. These are much-needed reforms for the BESS industry to grow to the volumes that are being projected as forecasts.

> "With the 'world's biggest BESS' crown seemingly changing hands every other month, it is an exciting time in the BESS arena, and the winners are the best prepared"

Planning is the not-so-secret sauce

The BESS market landscape is more competitive than ever. To build projects economically and achieve the target COD, developers need to plan to procure equipment smartly, forge strategic partnerships to secure production volumes for battery systems and take into consideration domestic manufacturing, although it remains to be seen how much of the touted domestic manufacturing will take shape in time to feed the enormous North American battery market. Interconnection fees have increased significantly as part of the queue reform and process times are expected to get shorter, so it is all the more critical to have 'firm' projects in the queue and certainty in the equipment planned to be used (specifically the power conversion system). It is also equally important to plan for BOP equipment in the form of tactical bulk ordering for medium-term projects in the pipeline as lead times stabilise to be the 'new normal'. EPC resources are an often-overlooked critical aspect as well – the bulk of the major EPC companies are spread thin between a growing list of developers and massive projects. The preconstruction and construction phases of projects are being pulled left and stretched. Hence there is emphasis on forming strategic partnerships and getting them onboarded as early as two years before the planned COD.

With the 'world's biggest BESS' crown seemingly changing hands every other month, it is an exciting time in the BESS arena, and the winners are the best prepared. ■

Author

Swetha Sundaram is the director of BESS project design at RWE Clean Energy, the fourth largest developer and owner of PV and storage projects in North America. She is responsible for development engineering and product management for energy storage projects. Before RWECE, she worked for DNV as a senior consultant in the energy storage independent engineering and advisory group, overseeing IE due diligence for the financing of several BESS and PV+BESS projects across multiple developers. Before that, she worked in the nascent BESS group of RWE Renewables, focusing on design tool development and operational modelling. She has also worked for Pacific Gas & Electric and AES Indiana in the energy storage planning and integrated resource planning groups.

From a big year for BESS to an even bigger one: Predictions and take-aways for 2024

Market trends | Andy Colthorpe takes soundings from key energy storage market players on their forecasts for the industry in 2024, following a year of significant progress in 2023

As each year draws to a close, Energy-Storage.news approaches a select few industry figures for their views on the 12 months just gone and the year ahead as part of our annual 'Year in Review' series.

Here are some quotes from the eight industry representatives we heard from this time around, as 2023's big year for energy storage ended and we welcomed 2024 with cautious optimism.

Looking back to 2023

What did 2023 mean for the energy storage industry, both from your own company's perspective and in bigger-picture terms?

The energy storage industry has continued to grow in 2023 – both in terms of the number and size of projects. Despite this growth, several important hurdles – including the rise in global interest rates – have held the US industry back. Projects are expected to be delayed into 2024 and beyond due to changes in local regulations, uncertainty around how policies like the Inflation Reduction Act/Green Deal will be implemented, and the market looking for stability in interest rates.

Andy Tang, head of Wärtsilä Energy Storage & Optimisation

Have supply chain constraints eased in 2023 and what sort of supply chain dynamics are you seeing in the industry going forward?

The supply chain disruptions caused by the COVID-19 pandemic have been mostly resolved, and their resolution is coinciding with an ease in demand for EVs, which means there is more lithium carbonate available to devote to energy storage projects.

On the battery front, more manufacturers are coming into large scale battery production, first spurned by the EV market and now into the energy storage space. That is a good thing for the energy storage projects: there is physically more supply coming off production lines and there is more innovation in energy density and safety features as manufacturers work to keep up and exceed each other.

Ray Saka, VP of business strategy and services, IHI Terrasun

The challenges we face in the supply chain continue to be diverse. The biggest bottleneck encountered in battery storage projects is still the long delivery times for high-voltage components, especially HV-transformers. This bottleneck is affecting projects throughout the industry and has increased further due to the strong expansion momentum.

At the same time, there are encouraging signs that the market for battery components, including modules, containers, inverters and switchgear, is easing. Delivery times for these crucial elements have normalized again to less than 12 months, depending on the size of the project. This easing of the market promises greater flexibility in the planning and implementation of our projects.

Florian Antwerpen, managing director, Kyon Energy

Looking ahead

What are some major trends in energy storage technologies that readers should keep an eye out for?

Lithium-ion. No, for real. In the solar sector in the mid-2000s, there were about a dozen competing technologies that triggered investment and media, but they all lost to the basic solar photovoltaic technology. Solar PV started getting deployed, creating an unstoppable feedback loop of incremental efficiency gains and supply chain consolidation. Over a 15-year timeline, that combination dominated the market.

Credit: Fluence

Despite challenges, our interviewees believe the industry is on a strong foundation for a big year in 2024

It's the same now with lithium-ion. Don't get me wrong, there are some really exciting technologies out there and I wish everyone the best but look at the cost curves. It's going to take a lot of time for the new entrants to come to the market in a truly cost-competitive way.

It's not sexy and doesn't get clicks – but watch and report on the incremental lithium-ion gains on the density and efficiency side. Pay attention to what's boring – that is what is going to have a big impact.

Jeff Bishop, CEO, Key Capture Energy

How are energy storage projects and different market opportunities evolving, as technologies and stakeholder understanding mature?

We see that stakeholders across Europe are recognising more and more the essential role that BESS plays to integrate renewables into the power grid. Policy makers, regulators and grid operators are key to setting the right framework for BESS capacity growth. In this sense, for example, grid connections, permits and grid fees are still slowing the deployment of BESS in many countries.

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However, we see that in most countries stakeholders are now actively pursuing strategies to reduce hurdles and to activate the BESS build-out. This is enabling us at Aquila Clean Energy to continue to grow our investment, development and construction activities in this space. We also welcome the approach of countries like Greece and Spain to set up dedicated incentive systems for battery projects.
Kilian Leykam, director energy storage, Aquila Clean Energy EMEA

What do you think 2024 will mean for energy storage?
The biggest year of new energy storage to date! At this point, each year we expect the global demand for battery-based energy storage systems to be larger than the previous, and that continues in 2024 – still driven by the largest global markets, but with newer markets starting to contract for large-scale storage as well.
Andrew Gilligan, director of commercial strategy, Fluence

Energy trading in itself is not a new concept, but the role of battery storage within that is perhaps one that many people are still learning about. What's the easiest way to explain what optimisers do?
Power traders traditionally have only been able to trade across markets or across the curve, but batteries allow power to be traded across time, which isn't otherwise possible. But it's not as simple as just charging the battery at night when the price is low and discharging during the day when the price is high. Power prices are very volatile so there are numerous chances to buy and sell every day, but at different times that are hard to predict and optimally trade across. And there are multiple power markets, state of charge, cycling, degradation costs to manage and so on.

As an optimiser it's our job to manage all of these variables and make sure a battery is in the right market, at the right time, all of the time, while respecting its operational parameters.
Dr Ben Irons, co-founder and director, Habitat Energy

What should the industry's main priorities be in 2024?
Education. Education. Education. As we talked about in our interview with *Energy-Storage.news* at RE+ last year, positive engagement with authorities having jurisdiction (AHJs) is vital for success in the US battery storage industry. We need to continue educating the AHJs on each project we're building and the change in technologies and what that means for their first responders.
Adam Bernardi, director of renewables sales and strategy, and Chris Ruckman, vice president of energy storage, Burns & McDonnell

To take full advantage of the opportunity storage systems present, there are several challenges we must look to address in the coming year. Firstly, we urgently need a paradigm shift in the political and regulatory community on every level to acknowledge the importance of storage. A key component to this is increasing the number of studies that emphasise the cost benefits and flexibility advantages of storage systems, especially to political decision-makers.

We also need political regulation to grant storage systems priority access to the grid and creation of market environments that offer many different applications such as wholesale trading, frequency and non-frequency ancillary services and capacity markets so that it becomes a more economically attractive venture to storage developers. The regulations in the European Renewable Energy Directive (RED III), as well as the planned approval of the new Energy Market Design, are steps in the right direction.

There must also be a concerted effort to get communities on board with storage systems. Community acceptance is a pivotal part of the success of any renewable energy solution. Although concerns must be taken seriously, these can be mitigated by planning, executing and operating projects to the highest social, technical and environmental standards.

Storage is a stable, sustainable all-rounder and, simply put, the successful energy transition depends on it. This is why there must be tangible progress made in 2024, from regulators to communities to storage operators, so that together we can take advantage of the benefits storage has to offer.
Julian Gerstner, head of storage, Baywa r.e.

Congratulations on being recognised for your Outstanding Contribution to the industry at the Energy Storage Awards 2023. What does being part of this industry mean to you, personally and professionally?
It has always been and remains a privilege to work with one of the most important asset classes there is within the transition to a low carbon society. I've been a renewable energy investor for many years and energy storage is the most complex and rewarding technology I've come across in what it can achieve to move us towards a sustainable future.

It gives me a huge amount of satisfaction in my daily working life to be surrounded by dedicated, knowledgeable and passionate colleagues using their talents to drive energy storage forward on a global scale.
Alex O'Cinneide, founder and CEO, Gore Street Capital ■

You can read the full 2023 series and previous years' editions on energy-storage.news

Last year's Energy Storage Awards, organised by *PV Tech Power* publisher Solar Media, gave the assembled industry in Europe the chance to celebrate

Credit: Solar Media

Designing a 200MW/800MWh BESS project in Italy

Case study | Engineering firm Benny Energia provides us exclusive insights into a 200MW/800MWh project they developed in Italy, where grid-scale deployments are set to soar over the next few years

Project overview:

- Battery energy storage system (BESS) project in Friuli Venezia Giulia, Italy, designed by Benny Energia
- Power installed: 200MW
- Energy capacity: 800MWh
- Charge and discharge hours: four hours

In the last two centuries, there has been a significant increase in the global demand for energy. However, the consequence of this growing demand is the uncontrolled use of fossil fuels. Fossil fuels have played a significant role in the increase of greenhouse gas emissions, triggering a severe environmental crisis.

Human activities contribute to the accumulation of greenhouse gases, causing a rise in global temperatures. This, in turn, leads to changes in snow and precipitation patterns, an increase in average temperatures, and a higher frequency of extreme weather events such as heatwaves and floods.

In order to address climate change, the European Parliament has voted in favor of the European Climate Law, raising the target to reduce net greenhouse gas emissions by at least 55% by 2030, compared to the current 40%, and proposing the legal obligation to achieve climate neutrality by 2050.

To achieve its ambitious goal of climate neutrality by 2050, the European Union is promoting the decarbonisation of the energy sector by gradually replacing fossil fuel energy sources with renewable sources such as wind, solar, and biomass. A significant added value in the decarbonisation process is provided by "sector coupling", which increases the need for flexibility and reliability while reducing the overall costs of the energy transition.

Sector coupling involves two complementary scenarios: the electrification of final consumption and the integration of energy networks and vectors. The first scenario ensures a strong penetration of renewable sources and a push for energy efficiency but requires a high need for flexibility in the network and the enhancement and extension of undersized transmission and distribution networks.

TSO Terna's 150 KV transmission network across Northern Italy.

The second scenario involves supplementing renewable electricity with other energy vectors such as biogas, biomethane, and hydrogen for applications in sectors difficult to electrify [1]. In both scenarios, energy storage systems play a fundamental role, allowing the matching of renewable energy production with demand when they are not simultaneous and storing excess energy to prevent wastage.

The project

Given the importance of energy storage systems in the context of the energy transition, Benny Energia has developed the largest battery energy storage system (BESS) in Europe, to be located in Friuli Venezia Giulia, Italy.

The project, submitted for approval in December 2021, is expected to be operational by the end of 2024.

The design of a BESS, the subject of this article, involves determining a suitable area for the system. The chosen area must meet criteria defined by customer's guidelines.

Location and suitability of land

Firstly, the area must be close to the substation, and its dimensions must allow for the placement of all containers and auxiliaries. The connecting roads between the airport and the site, as well as access roads to the area, must be suitable for the transit of vehicles needed for the transport of goods.

Additionally, the maximum slope of the site must be below 15% to optimize design.

Subsequently, after an analysis of the area within the regional territorial plan, it is necessary to assess urban and territorial compliance through an analysis of landscape, archaeological, and hydrogeological constraints. These are essential to evaluate the risk of possible landslides or seismic events that could lead to ground collapse.

The area identified for the 200MW BESS project is adjacent to one of the main Terna

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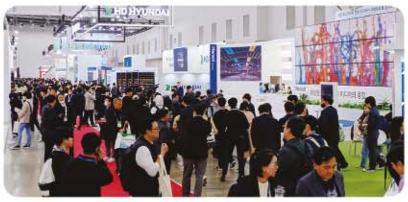

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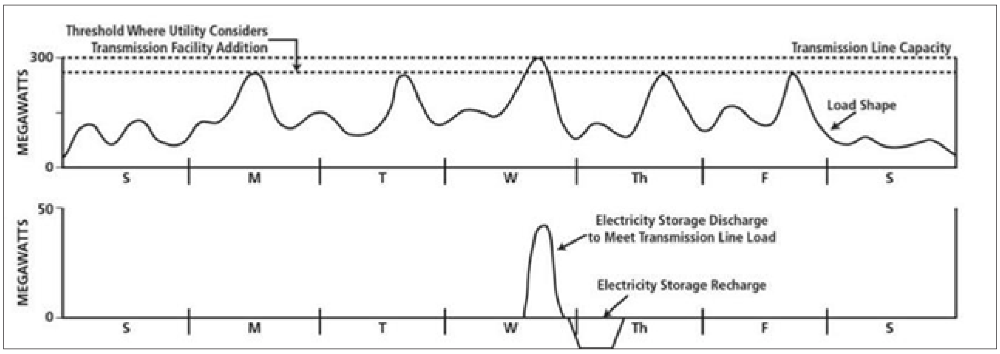
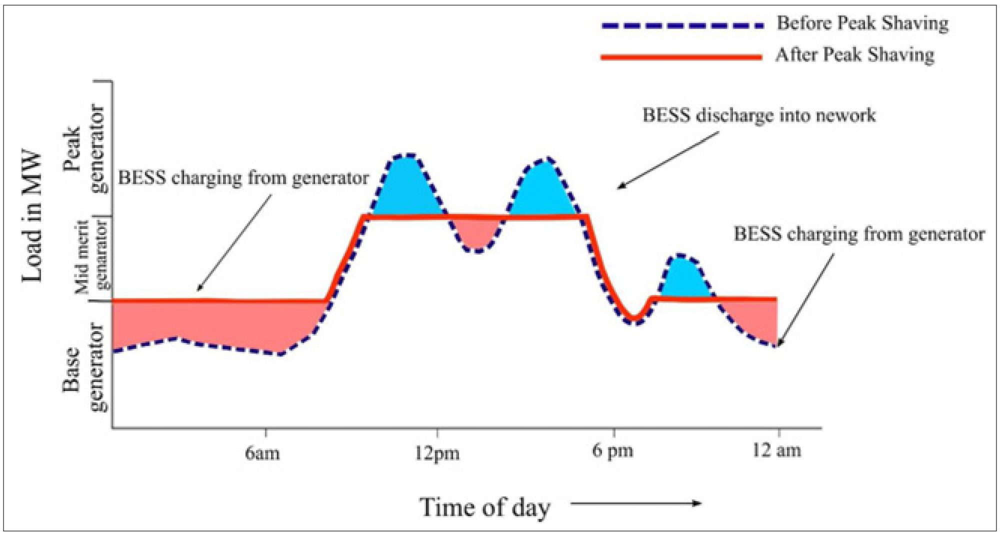


The operation of a BESS project over the course of a week.



The operation of a BESS project through the day.

substations in Friuli Venezia Giulia Region.

Using the QGIS software, an open-source Geographic Information System (GIS), the slope of the area and its non-interference with constraints have been evaluated. The slope analysis within the QGIS software can be performed using a Digital Elevation Model (DEM).

The DEM used, obtained from distinct DEMs of individual administrative regions of Italy, was provided by the Pisa section of the National Institute of Geophysics and Volcanology (INGV) and pertains to the elevation of bare terrain, also known as the Digital Terrain Model (DTM) [2]. The DEM is loaded as a layer and can be used to determine the slope of the area, resulting in a temporary layer automatically overlaid on the DEM that generated it.

The analysis determined that the identified area fell within a zone with a slope of less than 5% and was therefore suitable for the installation of the BESS system. To determine the suitability of the area, it was verified that the chosen area for the BESS system did not interfere with landscape and environmental constraints through overlays of the examined area on maps of the main constraints.

Firstly, Landscape Constraints under Legislative Decree 42/2004 were analysed as well as interference with landscape protection zones such as riverbeds and archaeological areas.

The examined area does not interfere with landslide scenarios and/or seismic events in the territory and complies with the flood risk constraint.

In fact, the area does not fall within flood risk zones and no interference was detected between the area of the BESS system and protected areas.

Configuration of the BESS project

The design of the BESS system involved a layout sized according to the availability of land use making possible a plant having an installed capacity of 200MW.

The plant layout consists of multiple of containers grouped into base units each equipped with its own Power Conversion System (PCS). Within the area, control cabinets necessary for supervision of the transformers in the area, control of measurements (voltage, current, frequency) and optimal working temperatures of the batteries were set up.

In addition, the connection wiring diagram describing the connection of each individual container of the entire plant to the Terna Station stall was made. The single line wiring diagram was equipped with all the necessary control and protection systems.

The design difficulties that Benny Energia encountered and overcame during the plant design phase were the presence within the area of an overhead HV power line, the need to maintain distances congruent with current fire prevention regulations, and finally the need to keep noise below an acceptable threshold.

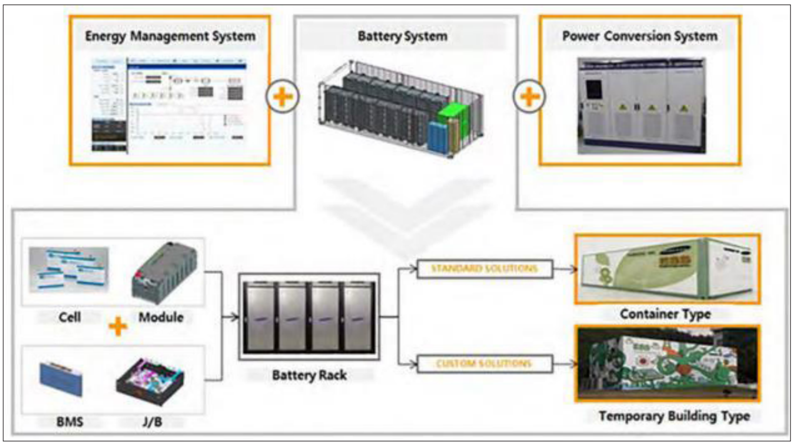
The BESS containers

In the BESS container, secondary lithium-ion batteries are housed, assembled in strings of batteries connected in series, installed in parallel to form modules. These modules, in turn, are connected in strings of modules in series and are housed in rack mounting structures.

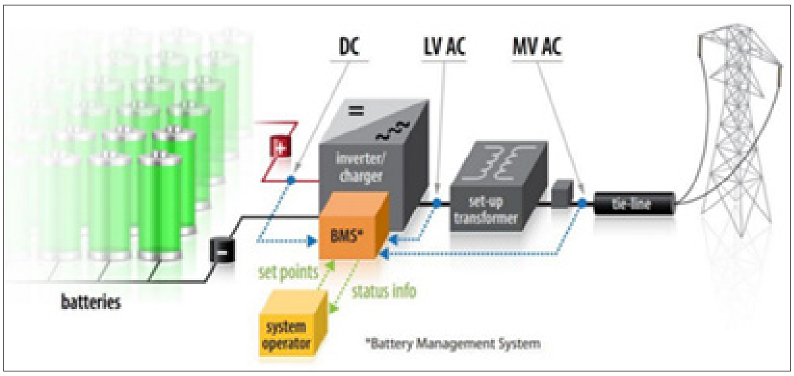
The battery racks are connected in parallel to meet the nominal energy capacity and are arranged inside the battery container.

Lithium-ion battery technology

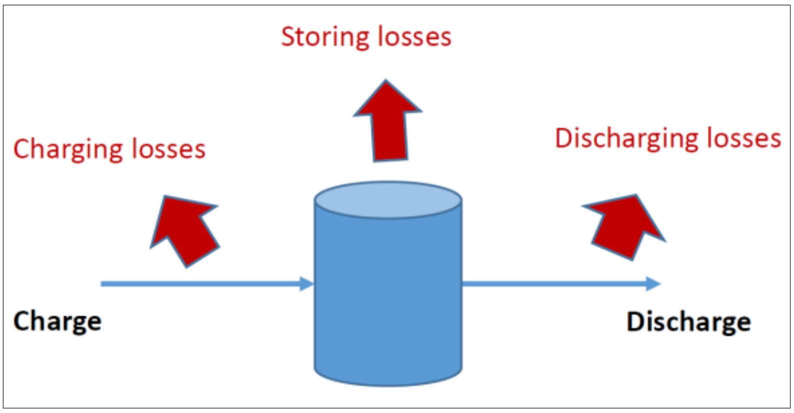
Lithium-ion batteries represent the most advanced technology in the field of electrochemical storage systems due to their high specific power. However, their



The composition of a BESS project, including BESS, PCS and energy management system.



How the batteries connect to the grid via DC, low-voltage AC and medium voltage AC connections.



Energy losses occur to some degree during all stages of a BESS activity.

main disadvantage is the high cost due to the need to implement safety systems to prevent overcharge situations.

Despite the existence of a wide range of lithium batteries with different cathode compositions, they share a common basic structure. These devices include an anode generally made of graphite and a cathode made of a metal oxide, and their assembly creates a layered or tunnel structure to facilitate the insertion and extraction of lithium ions.

The electrolyte, both liquid and polymer, serves as a link between the positive and negative electrode, which are separated by an electronic insulating layer, usually made of polyolefin. The electrochemical reactions vary depending on the type of cell, but the open-circuit voltage ranges between 3.6 and 3.85 V. Lithium batteries are high-energy systems and require extremely cautious handling.

Safety measures

Electrical, mechanical, and thermal abuses can cause problems in their operation such as thermal runaway that damages the cell and, in the worst cases, can lead to gasification and the release of flammable vapors containing solvents present in the electrolyte.

For safety reasons, the cells are often contained in robust metallic containers. One of the most critical aspects of lithium-ion cells is their degradation over time, which leads to a progressive reduction in capacity compared to factory data, even in the absence of charge/discharge cycles.

The system is equipped with a Battery Management System (BMS) capable of monitoring cell-to-cell variations over time: diagnosing errors, detecting safety hazards, and issuing warning signals. It records signals from the battery pack and individual cells, storing data related to the battery's lifecycle history. Additionally, it measures voltage, current, and temperature signals and monitors these parameters to achieve cell balancing and prevent battery damage. Finally, it determines cell and pack levels, such as State of Charge (SOC) and State of Health (SOH).

The container structure considered is self-supporting, metallic, for external installation, built with profiles and insulated panels and is designed for outdoor use. Profiles and insulated panels are used. This design allows the entire system to be transported and installed without the need to disassemble the various components of the container, except for the battery modules, which could be disassembled and transported separately if necessary.

The containers have standard dimensions. Each container is equipped with environmental sensors, including those for temperature and humidity, to constantly monitor internal conditions. If required, the containers have an air conditioning and ventilation system to ensure optimal environmental conditions for the proper functioning of various components. A liquid cooling system is also present.

To prevent emergency situations, the internal temperature of the container is monitored using thermocouples, especially for detecting possible fire residues. The container is protected against the entry of dust and water jets from various directions, providing a safe and secure environment for the energy storage system. ■

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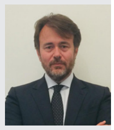
Authors

Eng. Diego Margione is founder and CEO of Ergon Group Srl, partner of Benny Energia Srl for the for the scouting and development of Renewable Energy Plants. He has 20 years of experience in the field of mechanical engineering as a designer, consultant, and developer in renewable energy.



Dr. Andrea Giulio Barone, founder and CEO of Benny Energia Srl, has more than 20 years of experience in structured finance and 10 years in the financial, economic, and managerial sectors of renewable energy.

Eng. Marta Maiolati, development manager at Ergon Group Srl, has over 10 years of experience in the design and development of renewable energy plants, and has worked on over 300MW of solar PV and 3.5GW of BESS.

Eng. Filippo Onori, PhD student at Ergon Group Srl and Marche Polytechnic University, worked on a thesis for a master's degree in mechanical engineering on the design and management of the 200MW BESS plant.

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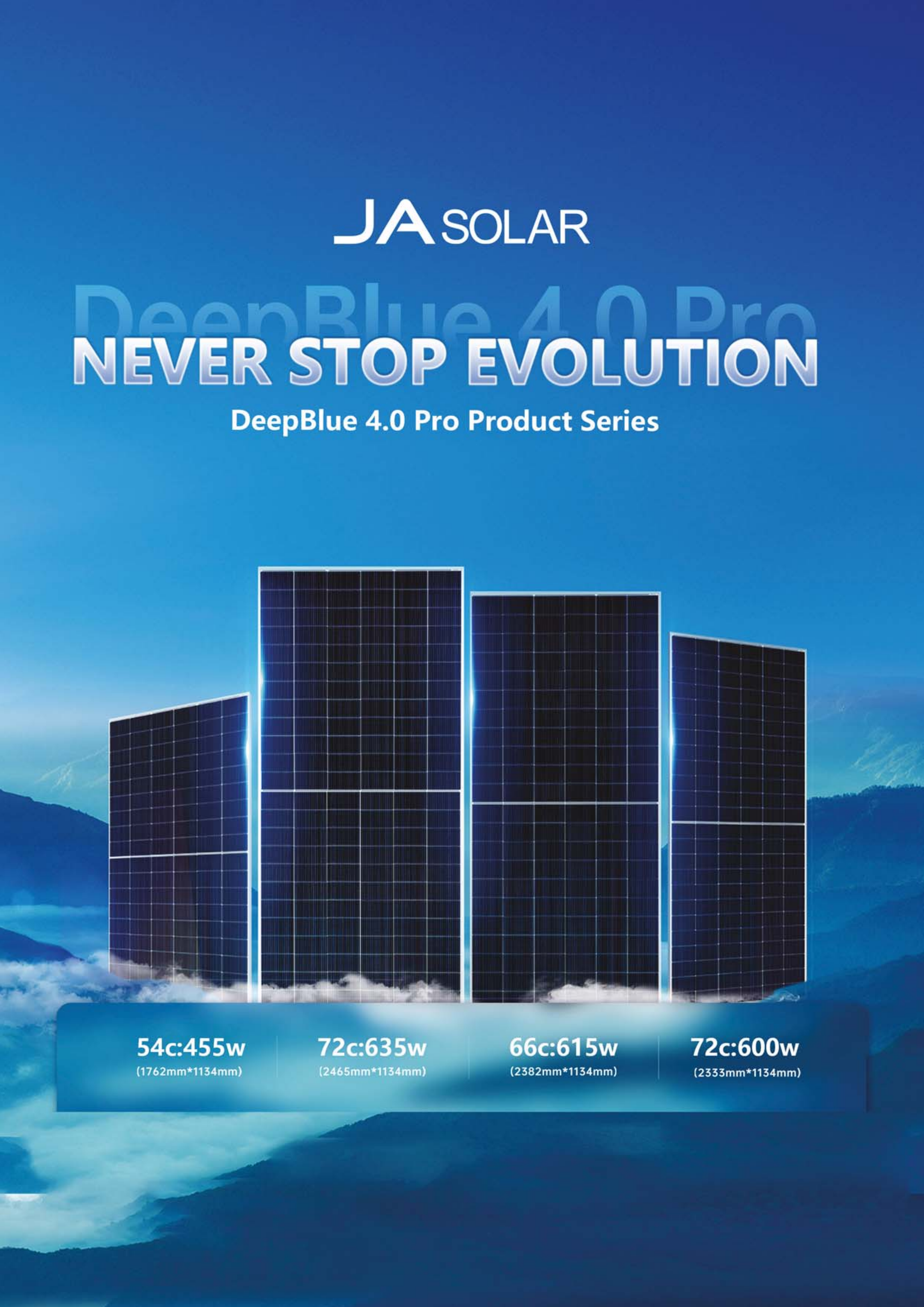
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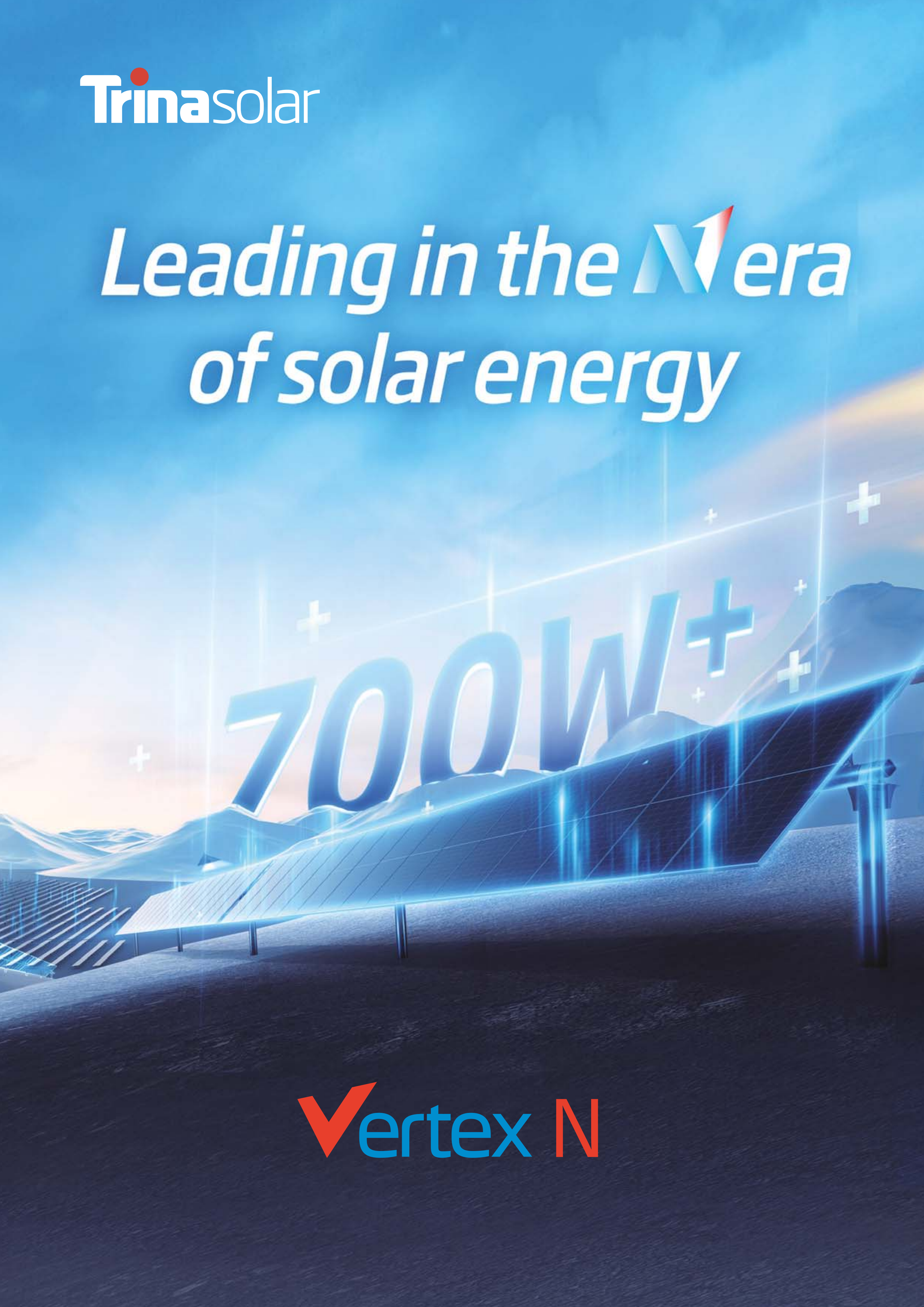
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