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Shaping up for an EU supply chain

Enel Green Power's plans keep Europe in the solar manufacturing frame

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enel Green Power

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Enel Green Power and 3Sun: PV Gigafactories on both sides of the Atlantic

Photo: pv magazine/Thomas Beetz

As I write these lines to introduce this Special Edition, a major American newspaper has just reported on Enel Green Power's plans to build a 3 GW solar module production plant in the US, scaling up to 6 GW in the coming years. Like other solar PV manufacturers, Enel is responding to the Inflation Reduction Act (IRA), an historic legislation signed by President Biden this summer.

The IRA provides so-called "Advanced manufacturing production credits" to cell and module manufacturers like Enel's subsidiary 3Sun. For example, €0.066 (USD 0.07) per watt is provided to manufacturers of PV modules. At the same time, downstream ground-mounted and rooftop projects can receive an additional investment tax credit for using "Made in America" panels.

This combination, established for a period of ten years, has sparked a renaissance of US PV manufacturing. In Europe, there is arguably even more potential for a manufacturing boom, since the region suffered less of a decline in manufacturing jobs, know-how, and production sites compared to the US in recent decades. In addition, Europe has significant research and development expertise in PV technology, such as the Fraunhofer institutes in Germany or The National Solar Energy Institute arm of the French Alternative Energies and Atomic Energy Commission. It also has a large market clamoring for clean energy to decarbonize its energy supply and limit global warming.

In this context, it is a bold and historic move for Enel to develop PV gigafactories on both sides of the Atlantic to help drive the reshoring of PV production and technology development. Enel's European gigafactory in Catania, Italy, is the opening move in this European-US gigafactory rollout with the Catania facility acting as both guide and inspiration for the company's plans in North America. On both sides of the Atlantic, the war in Ukraine has made it a matter of national security to build up energy supply chains that can be relied upon during the transition to a carbon-free energy system. The potential for a solar energy bedrock in Europe means it's critical that the PV supply chain be ramped-up. This does not mean a complete shift from non-European producers to European suppliers, but rather a healthy balance between "Made in EU" products and products imported from abroad.

We are honored to produce this special edition with Enel Green Power, a global leader in the development of PV power plants and PV technology. In this edition we take a close look at the company's first gigafactory in Catania, Sicily. And we also describe the very innovative bifacial heterojunction cell technology that Enel and its manufacturing subsidiary 3Sun are deploying at this factory. In the next two years this production hub will scale from 400 MW to 3 GW and produce state-of-the-art "Made in EU" modules for both the utility-scale market (640W to 680W panels) and the commercial and industrial market (440W to 480W). Module efficiencies will be over 24% and all panels produced at the 3Sun Gigafactory will offer a higher resistance to mechanical stress than panels utilizing conventional TOPCon or PERC cell technologies.

Demand for these high-quality n-type heterojunction modules has already filled 3Sun's order books up until the end of 2024. We can expect more of the same as Europe strives to reach the mark of 600 GW of installed PV capacity by 2030 and Europeans become even more concerned about sustainable supply chains and products. Sustainability is writ large at Enel Green Power and 3Sun, a fact that will become apparent as you turn the pages of this special edition.

Europe is poised to reemerge as a global leader in PV manufacturing not only at the cell and module level, but further upstream as well. Enel Green Power and 3Sun are pioneering these efforts and are also calling on other players to partner with them to build a strong and resilient PV supply chain in Europe. At **pv magazine** we will be reporting on these initiatives as a large part of these 600 GW in Europe promises to be highly sustainable "Made in EU" modules.

We at **pv magazine** hope you enjoy this Special Edition looking forward to a robust renaissance of European PV manufacturing. European manufacturing is back, and as it will anchor our energy transition in the decades to come, we're glad that it's here to stay.

Eckhart K. Gouras, Publisher, pv magazine

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Photo: Enel Green Power

A tale of solar resilience

Before the collapse of Europe's PV manufacturing sector the notion of building a large-capacity solar module factory didn't seem so ambitious. But in recent years that same goal required new partnerships, political will and a great deal of resilience.

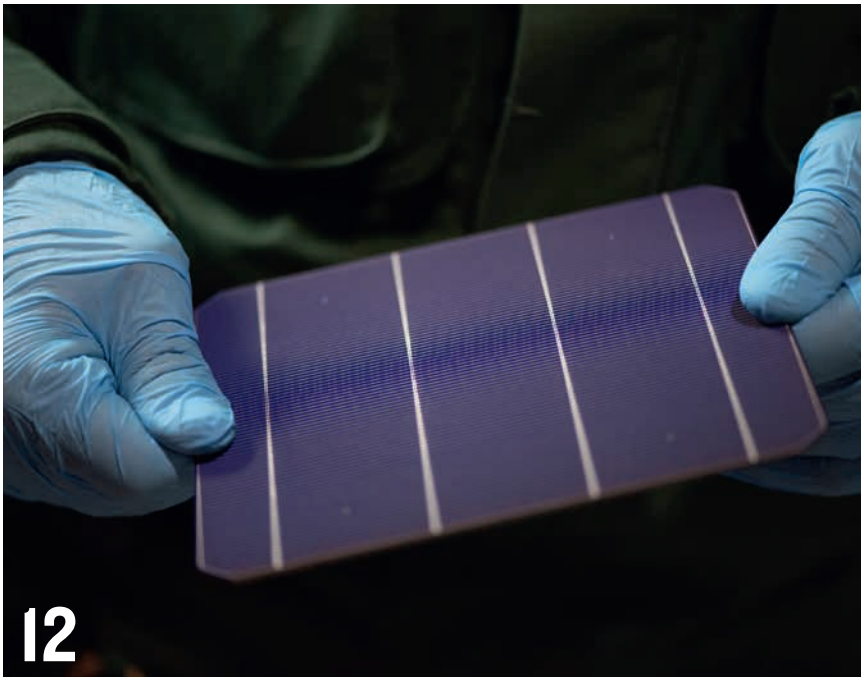


Photo: Enel Green Power

One cell to rule them all

HJT cell technology has long promised enormous potential, however, recent technological and price-point improvements mean that potential is now on the verge of realization, and at scale.

enel
Green Power

We can grow with more sustainable power.

Our wind, hydro, geothermal and solar power plants have transformed the way we produce energy, energy that comes from nature, directly into our homes. All thanks to sustainable technologies and solutions.
A commitment that has enabled us to become a world leader in renewable energy, with the goal of tripling our capacity by 2030.

Choose a better tomorrow.

A tale of solar resilience

Building a solar module factory in Europe in the first decade of this century was a relatively straightforward proposition. Across countries such as Germany, Spain, Italy, France, and the United Kingdom, manufacturing facilities produced polysilicon all the way to finished panels, with a solid supply chain, and corresponding demand. However, the rise of gigawatt-scale PV manufacturing in Asia, and technology maturity, challenged European primacy. Adding new solar manufacturing has become far more risky, though bold moves are being made with new partnerships and political will.

Enel Green Power's module production site in Catania, Sicily has been operational since 2011.

Photos: Enel Green Power

The origins of Enel Green Power's 3Sun solar module factory in Catania date back to January 2010, when the Italian renewable energy company signed a deal to build the facility with Swiss semiconductor manufacturer STMicroelectronics and Japanese electronics manufacturer Sharp. The trio agreed to set up new PV module production at an idled facility owned by the Swiss company and said the module technology would be based on amorphous silicon thin-film solar cells developed by the Japanese conglomerate. The factory was originally planned to produce both cells and modules, with an initial 160 MW annual capacity, expanding to reach 480 MW at a later stage.

This announcement caused a sensation at the time and created a lot of expectation both within and outside the solar industry. The decade of limited competition had come to an end, making the pathway to creating new PV manufacturing facilities more complex. But here three industry heavyweights had joined forces to enter one of the most difficult businesses in the then nascent renewable energy sector.

The factory was inaugurated in July 2011, with many questioning whether European manufacturers would be able to compete with Asian producers in terms of price and capacity. Others asked if a power utility such as Enel should enter the manufacturing business in general, and the solar panel business in particular. Others stressed the marginal role of the thin-film PV technology in the market and its difficult prospects in terms of growth both for volume and efficiencies.

Hard times

These challenges, however, were not the biggest the factory faced, as another storm was approaching. At the time, the global solar market was driven by Germany, Italy, Spain, and France, which were implementing generous feed-in tariff-based incentive schemes and seeing big growth volumes in terms of installed solar capacity. Alarmed by increasing public expense, governments in these countries decided to significantly reduce or eliminate the necessary support for solar energy generation. PV technology was then still some distance from reaching grid parity with conventional power generation technologies, such as coal-fired power stations, although that gap was rapidly narrowing thanks in large part to those government-led feed-in tariffs.

Most of us remember the diastrous results. Between 2012 and 2016, demand for PV in Europe collapsed. A wave of bankruptcies laid waste to many solar companies and module manufacturers across the continent. Thankfully, Enel and its partners were not among them, but the future of the 3Sun factory seemed precarious.

In July 2014, Sharp and STMicroelectronics left the joint venture and Enel took full control of the facility. The two departing companies paid out a total of €110 million and relinquished all obligations to the group as well as to the 3Sun manufacturing project.

"Between 2012 and 2016, demand for PV in Europe collapsed. A wave of bankruptcies laid waste to many solar companies and module macufacturers across the continent. Thankfully, Enel and its partners were not among them"

Shift to heterojunction

Despite these hurdles the factory never closed and production continued. However, in March 2017, Enel announced a decision to invest €80 million in the facility's conversion to silicon heterojunction PV technology production. The last thin-film module produced by 3Sun rolled off the line on October 25, 2017, with total production output reaching about 6.8 million panels.

The new factory had an initial annual capacity of 200 MW and production started two years later, in October 2019. "We are the first company in the world to produce photovoltaic panels based on the innovative bifacial HJT heterojunction technology on an industrial scale," said the head of 3Sun at the time, Antonello Irace.

The resumption of production was partially financed by Horizon 2020, the European research and innovation program, along with the Italian Ministry of Economic Development, the Sicilian

“The EU’s contribution amounts to €118 million of the €600 million expansion project”

regional government, and incentives for Smart Factory 4.0 development.

Scale

At this stage the key to competiting with the Asian solar manufacturing bohemoths was still missing – scale – a crucial factor impacting production costs and enabling affordable module prices. To see this scale materialize took some time. However, thanks to funds secured from the European Union, Enel will now be able to scale up the factory to 3 GW annual capacity in coming years.

“The innovative bifacial heterojunction technology ensures higher performance with respect to conventional modules, thanks to the intrinsic characteristics of the advanced bifacial structure that allows for the maximization of energy production while minimizing the cost of electricity (LCOE) in utility-scale installations,” said the European Commission in a statement.

The EU’s contribution amounts to €118 million of the €600 million expansion project, named TANGO (iTaliAN pv Giga factOry). “The 3 GW production facility is expected to be fully commissioned by July 2024, after starting with the first 400 MW in September 2023, making 3Sun Europe’s largest gigawatt-scale factory producing high-performance bifacial PV modules,” the company stated. The factory’s 200 MW line has now been idled to enable the deployment of this first 400 MW line belonging to the expanded 3 GW scheme.

Talent

The story of the factory not only shows the success of a solid industrial project, but also that of the individuals forming the team behind the 3Sun factory. Daniela Percipalle, power generation procurement at Italy 3Sun Business Unit, says the difficulty, at least at a first glance, of associating Enel with solar module manufacturing is emblematic of the team’s success.

Percipalle was hired as a buyer of control instrumentation, new equipment and maintenance services for the first factory’s launch in 2011. At the very beginning, she said, nobody seemed to acknowledge that something new was being done in Catania. “Up until that point, few people outside the photovoltaic sector had even heard of us; even in Catania, many people just knew 3Sun Gigafactory as one of the many factories located in its industrial district. Even so,” she continued, “they often displayed very little understanding of the situation: some acquaintances started contacting me when they were having problems with their power bills or to get an estimate for solar panel installation on their roof.”

Constant learning

The real challenge for Percipalle, however, came with the shift towards heterojunction. “For me it was an exciting new challenge: new suppliers, new materials, and lots to learn.” The first challenge was to learn how to successfully manage change in order to stay competitive. It was strategically important to get the best deals from a technical and commercial point of view with a particular eye on making a product that could also be sustainable.

The experience of Eleonora Arena, initially hired in 2012 as a computer engineer for the management of the MES (Manufacturing Execution System) and then covering the role of data analyst, is similar to Percipalle’s.

Arena deals with a highly complicated artificial intelligence modeling and anal-

ysis tool and the challenge is keeping up with constant innovation. "We have to come up with new solutions, inventing new ways of working each day," she said.

A key aspect of the predictive and explanatory power of a model is the amount, heterogeneity and quality of the data. The result is that she is contributing to the design of the digitalization of the new production line in order to make it an inexhaustible source of data, as well as energy.

The MES, which can be considered a bit like the "brain" of production as well as the "treasurer" of data, together with countless other data sources, typical of industry 4.0, allows Enel Green Power to implement artificial intelligence models aimed at continuous learning and improvement of the final product. The start of the 3Sun Gigafactory will not be the arrival point but will create infinite and exciting case studies that can be answered thanks to these models.

Antonio Ragonesi, the Head of Module Assembly Technology Transfer at Enel Green Power, was also on board for the construction of the factory since the early stages of development and had the chance of learning the tricks of the trade from his Japanese colleagues from Sharp.

"It was a wonderful time of reciprocal cultural exchange, rich in surprises not only in terms of the technology, but also our working life," he said. "The production simulation trials lasted up to 72 consecutive hours, continuing even through the night. And we observed behavior that seemed to us unusual, to say the least. Our Japanese colleagues were able to fall asleep during breaks while sitting cross-legged on the floor and then, as if by magic, they would wake up when it was time to resume work. I presume that they were finding some of our behaviors unusual too, but at the end of the day we bonded and really created a strong sense of comradeship."

All in all, these human experiences shows that the solar energy business, regardless of the geographic location and the market conditions, is not easy to handle, unless resilience is embraced. pv

Today, the factory produces silicon heterojunction cells and modules. Enel has made multiple investments to esnure the factory produces the latest in PV technology.

Reshoring the PV industry

Enel Green Power's 3Sun Gigafactory is installing machinery to reach its full 3 GW capacity by July 2024, eyeing advanced development which would allow the modules to compete in terms of durability, degradation and efficiency. In 2025, Enel's subsidiary will combine heterojunction with perovskite tandem technology to exceed 30% efficiency. Eliano Russo, head of the 3Sun Gigafactory, explains the company's strategy and warns that if Europe wants to achieve energy independence, it needs to create a supply chain capable of producing 40-50 GW per year.

Reshoring the photovoltaic industry in Europe is possible, provided companies invest in innovative technologies with the support of the European Union and national governments. So says Eliano Russo, head of the 3Sun Gigafactory in Italy, which is set to become Europe's largest PV production facility. "Today, our cells are certified at an efficiency level of 24.6%. We have a development roadmap that will lead us to couple heterojunction with tandem technology, introducing perovskite to broaden the spectrum we can absorb," says Russo.

He explains that the developments in China, where smaller players are also moving to HJT, confirm that the technology is the right way to continue innovating and gaining market share. At the same time, it sets an example for European players to create a supply chain and industry ecosystem together.

The 3Sun Gigafactory now has a competitive advantage due to the knowhow accrued internally, and thanks to collaborations with leading research institutes such as The National Solar Energy Institute arm of the French Alternative Energies and Atomic Energy Commission. But investments by other European companies are equally necessary. "We must run because the advantage gained in these five years will gradually close. We must keep innovating and do it faster than others," Russo adds.

Speed is not the only factor in reaping the benefits of investment; scale is equally important. Enel is exploring different options to expand Catania's existing capacity and complement it with other activities that favor vertical integration. To that end the company is looking at the world of wafers and polysilicon production, pondering horizontal integration, and is keen to replicate the Catania facility's example in different geographies.

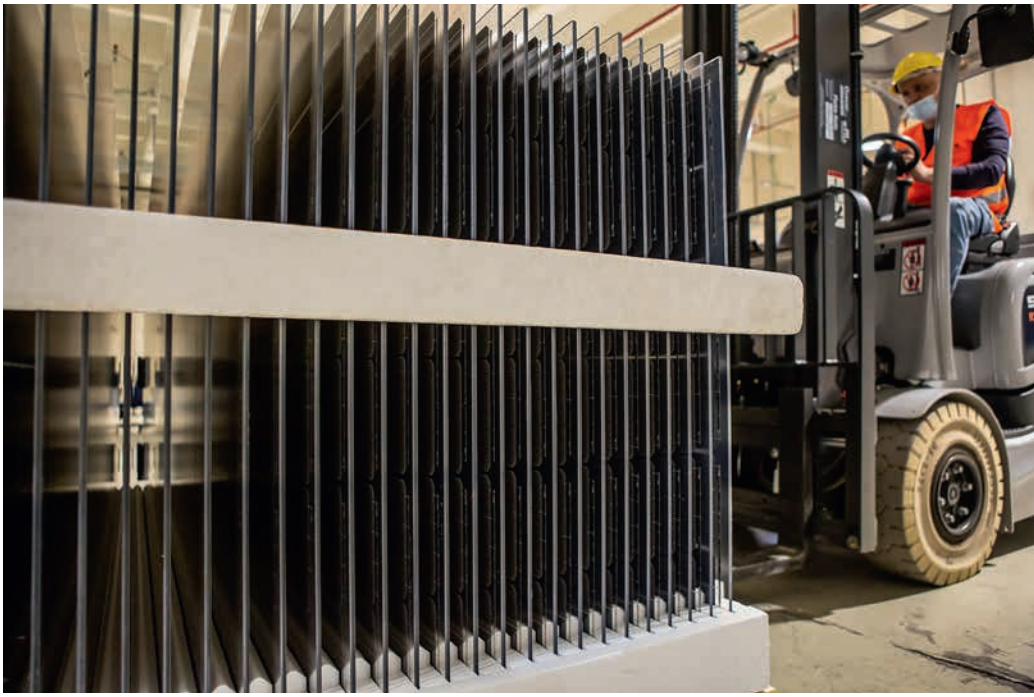
The aim is to gradually decrease European energy dependence in the coming years, eventually achieving substantial independence after 2025. "Our factory in Catania, while the largest in Europe, is only a first step. If Europe wants to reach the target of 600 GW of installed capacity by 2030, it must set up a production chain capable of producing 40-50 GW per year. We cannot delude ourselves that by making the cells and modules, but buying the materials elsewhere, we can achieve energy independence," says Russo.

Plans are in place to install 10-15 MW of solar at the 3Sun Gigafactory. In combination with PPAs, this will allow the site to be powered by 100% renewable energy.

Public support, private investment

Enel's position is consistent with that of the European institutions, which have repeatedly explained that support from the member states and the European Union is a precondition for raising the technological profile required for reshoring the sector. "What has happened in China over the last ten years is also due to government support that we have quantified at something over USD 150 billion," says Russo. The head of 3Sun Gigafactory

Photos: Enel Green Power



Careful choice of suppliers for all the materials that go into Enel Green Power's HJT modules is key to the company's strategy for reducing supply chain risk.

adds that the US is presenting a plan of a similar order of magnitude.

Support modes can vary, including grants, tax credits, and direct payments. Enel Green Power has benefited from European grants through the Innovation Fund. "Localization support as India is trying to do is an option too. India is introducing import taxes to localize the production chain. Demand-side incentives are also useful, like the Ecobonus and Superbonus in Italy or the investment tax credit for those who buy panels in the US," he underlines.

Enel is currently looking within the European Union and the United States. "We are evaluating the different options. The recent passage of the Inflation Reduction Act in the US is shifting the balance. In light of these regulatory developments, we are trying to understand the optimal configuration," Russo explains. "Europe should soon translate good intentions into concrete actions. We think this will happen soon."

Using the Innovation Fund, the company will have a constraint to allocate at least 60% of production to European markets. Several North American companies could become customers too. "We expect that those markets with greater environmental awareness and desire for greater energy independence will be the ones that appreciate our product the most. Europe, the United States, for sure. We are studying the other markets: LatAm, India, and Asia in general," says Russo.

The panels produced in Catania will be priced a few cents per watt higher than many of its competitors. "But if customers think in terms of LCOE, all the inherent characteristics of the panel, such as efficiency, longer life, lower degradation, make the customer's return on investment higher," says Russo. The panel should have an average lifetime of more than 30 years.

Environmental standards

Enel Green Power explains that it focuses on production processes with a high level of automation that avoid waste and encourage materials recycling. The Catania factory is also paying attention to the entire supply chain. "We make sure that wafers, glass, plastic, encapsulant, and silver paste are produced by our suppliers in line with best practices in terms of traceability and labor laws. This policy narrows the landscape of possible suppliers but gives us guarantees."

The 3Sun Gigafactory self-generates its energy and expects the share of renewables to increase gradually as the factory's capacity expands. "In the future, we will find the right balance between self-generation, where in addition to conventional generators, we will install 10-15 MW of solar, and the purchase of renewable energy through PPAs. This is to ensure that Scope 2 is carbon-free," explains Russo.

The company expects energy prices to go down in the medium term but not to fall drastically. "Producing energy at home is, therefore, a key element." The choice of suppliers also plays a key role in the company's road map to increase environmental standards, while decreasing the supply chain risks.

"The strategy to manage production from 2025 onwards is based on working with local manufacturers or new entrants to ensure that there is additional supply of polysilicon outside China," says Russo. From March 2023, the company will start receiving materials. "We are closing medium- to long-term contracts that will allow us to go beyond the 2023-2025 horizon." pv

"The 3Sun Gigafactory self-generates its energy and expects the share of renewables to increase gradually as the factory capacity expands"

EU support for the solar

Enel Green Power has launched the 3Sun Gigafactory at a time when solar manufacturing is moving into new regions worldwide, and Europe is keen to meet a significant chunk of its demand for solar energy without having to rely on other parts of the world for supply. With this goal in mind, the company received €118 million toward its solar module factory in Catania from the European Union's Innovation Fund.

The European Innovation Fund distributes around €38 billion (depending on carbon price), taken from the revenues of the EU emissions trading scheme, and focuses on "highly innovative technologies and big flagship projects within Europe that can bring on significant emission reductions," according to the fund's website.

That Enel Green Power (EGP) was able to secure substantial funding for its project is a clear demonstration of its leadership among the many innovative technologies in solar manufacturing. The European Commission evaluates projects on innovation, project maturity, scalability, cost efficiency and potential for emis-

In addition to seeking local suppliers for its materials and components, Enel Green Power has ensured that much of the machinery that the 3Sun Gigafactory will run on is also being supplied by local players.

Photo: Enel Green Power

renaissance

sions avoidance. Projects are analyzed in detail by independent experts from the relevant field. "The competition was really, really tough, and for EGP it is really a big success," Maria Velkova, deputy head of unit for low carbon solutions at the commission's Directorate-General for Climate Action, told **pv magazine**. "In the first call, which was for €1 billion, more than 300 projects applied, 70 were selected for a second phase and we were able to offer funding to seven projects."

Through the recently launched REPowerEU initiative, the European Union aims at creating the conditions for the continent's energy independence and reducing its reliance on Russian fossil fuels. This initiative includes a Solar Energy Strategy to bring the region's installed PV capacity to over 320 GW by 2025 and almost 600 GW by 2030. "By creating the right framework conditions, the EU can expand its manufacturing base, building on its vibrant competitive and innovation-driven environment while ensuring that solar products are up to the EU consumer's high standards," the European Commission recently said in reference to the plan.

With the EU now placing higher importance on domestic manufacturing, the EU Innovation Fund's next call for large scale projects should make up to €3 billion in funding available, with a dedicated category and budget for manufacturing projects.

"In the first two calls it was completely open, just the best projects on the five criteria," said Velkova. "Now we will make the priorities more clear, and it is so important to support manufacturing in the EU."

Local technologies

One notable aspect of the 3Sun project is that many of the technologies set to be deployed in the factory are being supplied by European equipment manufacturers, for whom the project is something of a lifeline after several years with little demand, especially from local projects. In June 2022, German company 3D-Micromac confirmed that it would supply its cell cutting tool to the project.

"3D-Micromac's microCELL systems are proven in heterojunction solar module and cell manufacturing, and all of our experience from these past installations will be fully utilized to support this major expansion project," stated the company's CEO Uwe Wagner, announcing the partnership. "As the Enel Tango project shows, the future of the PV industry in Europe is very bright, and 3D-Micromac looks forward to being a strong partner in supporting the growth of the PV market in Europe, as well as around the globe."

The EU innovation fund will contribute

€118 million

to the 3Sun Gigafactory

One cell to rule them all

3Sun Gigafactory will produce n-type HJT cells to serve utility scale, C&I, and residential customers with outstanding specifications to offer a compelling LCOE case – and production will not be captive to Enel Green Power projects.

Enel Green Power made a clear strategic choice when it came to defining its solar product range. For all its panels, regardless of the size or the segment where they will be utilized, it bet on a sole solar cell technology – an n-type heterojunction (HJT) cell with an efficiency of 25.5%. "Our cells are all based on G12 wafers based on n-type silicon," said the head of Sales and Marketing, Massimiliano Francone. "With this cell configuration, we can achieve module efficiencies above 24%."

The cell has a thickness of 150 microns, but the company's roadmap has set a target to slim this down to 120 microns by the end of 2025. "Our cell is flexible and, compared to TOPCon and PERC cells, has a higher resistance to mechanical stress," said the head of 3Sun Gigafactory, Eliano Russo. "We conducted several tests which showed that if microcracks arise, they don't expand as significantly as in PERC cells."

The cell efficiency was certified by the Institute for Solar Energy Research Hamelin in Germany. "According to our roadmap, however, we should be able to increase to 25% efficiency in 2025 and over 26% in the second half of 2026," added Russo.

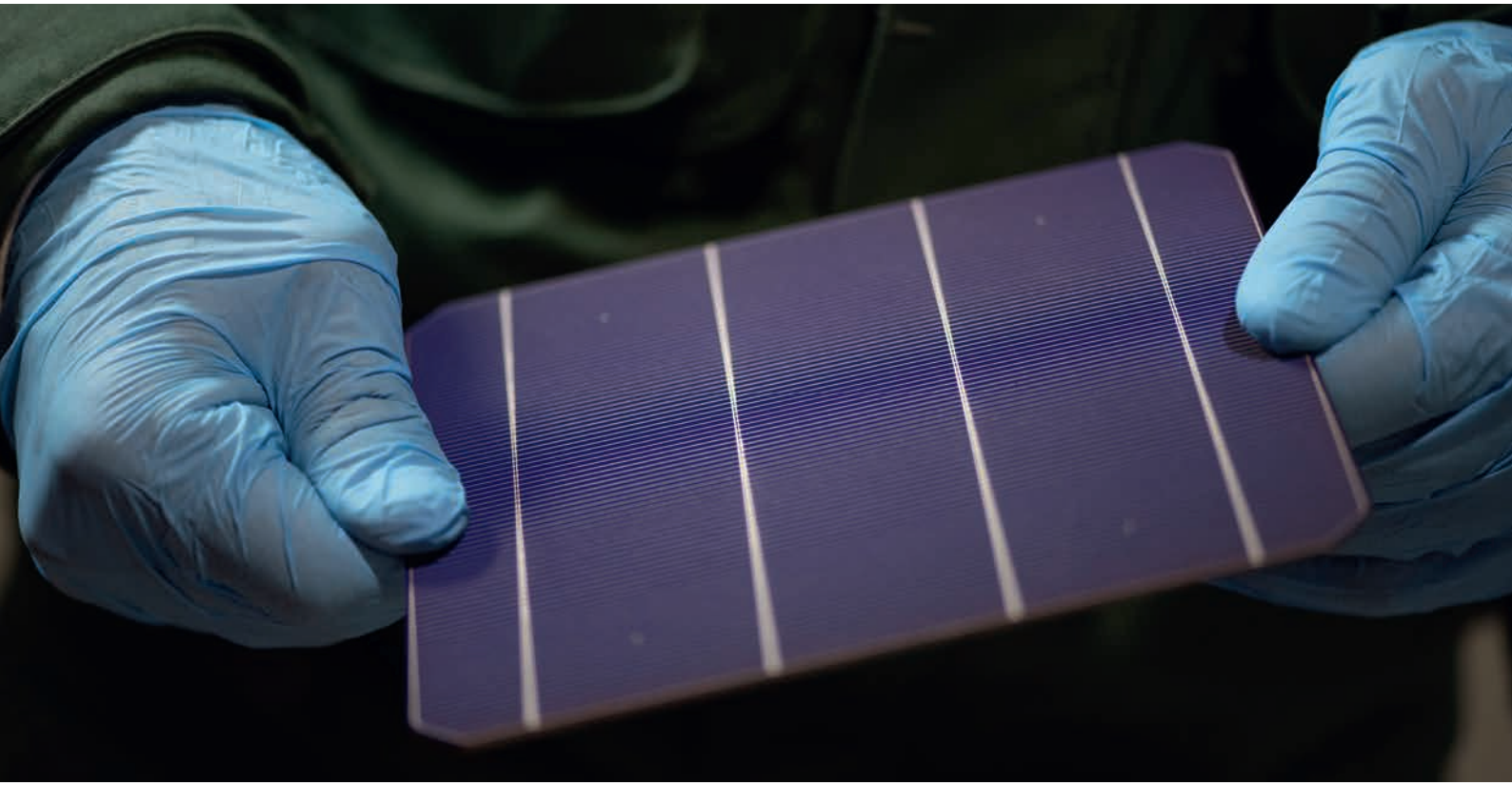
Enel Green Power has split 3 GW of manufacturing capacity, planned to be fully operational in the first quarter of 2024, into 2 GW of modules for utility-scale projects and 1 GW toward panels for distributed generation systems. "Production for the utility-scale segment should begin in Q4 2023 and the first shipments should be made in early 2024," explained Francone. "As for the rooftop business, the first modules should be rolled out from the lines in 2024." The company will target the EU27 market, where up to 60% of its products must be sold and installed to comply with the request of the EU Innovation Fund, that will provide a significant amount of funding for the project. "But we are also considering expanding our sales outside Europe," Francone emphasized. "We may also use part of the modules produced for EGP's own projects, but 3Sun won't be a captive factory."

Initially, Enel Green Power will set up the factory to produce 2 GW of modules for the utility-scale segment, and 1 GW of smaller-dimensioned products destined for rooftops and distributed generation projects.

Utility scale tech

The product for the utility-scale business is a high performance HJT PV bifacial module with higher efficiency, lower degradation, better temperature coefficient, better performance in low light conditions, and a bifaciality factor that reaches 95%. "With these modules we are targeting customers that are aware of the technical advantages of the heterojunction technology and are seeking a premium product," Francone said. "This premium is a crucial factor allowing developers to achieve a lower levelized cost of energy (LCOE), thus improving

Photos: Enel Green Power



Enel Green Power's modules are based on 210mm heterojunction cells that reach 25.5% efficiency. The company also states that its cells are more flexible than others on the market, making them less vulnerable to performance-damaging cracks in the field.

project profitability." The panel is available in nine versions, with power outputs ranging from 640 W to 680 W and average efficiency spanning from 22.6% to 24%.

All versions of the solar module measure 2,172 mm × 1,303 mm × 35 mm and weigh in at 36 kg. The maximum system voltage is 1,500 V. The panel can be used in operating temperatures ranging from -40 C to 85 C, with an operating temperature coefficient of -0.24% per degree Celsius. It is enclosed between 2 mm solar glass with anti-reflective treatment, and features a junction box with an IP 68 rating and an anodized aluminum frame.

The new products come with 30-year linear power output guarantees and 15-year product guarantees. The degradation in the first year is purportedly 1.0% and the 30-year end power output is guaranteed to be no less than 91.7% of the nominal output power.

Despite the slightly higher price compared to conventional monocrystalline PERC products, which Francone said could be easily compensated by the much lower LCOE that the product is able to deliver to the projects, providing a great advantage to investors and developers. According to Francone, the total production output for these panels is already fully booked for 2024 and new orders are currently being taken for 2025. "Demand for heterojunction panels is huge. Solar project developers in Europe are resorting to us as they not only want high-efficiency products but also modules Made in EU," he said. "I cannot quantify exactly the economic extent of this market trend, but we see continuously mounting demand."

Rooftop & perovskite

The modules for both commercial and industrial projects and residential are monofacial panels with a power output range from 440 to 480 W, and much smaller dimensions compared to the utility-scale product. "Production for these modules, which are also designed to be in the premium segment, should begin in 2024," specified Massimiliano. "The first shipments should be made in the second half of 2024."

Starting from 2026, Enel is also planning to launch even more efficient solar modules based on tandem silicon-perovskite cells. "This is not simply an R&D development," Massimiliano stated. "We are planning to roll out commercial products from our lines and to immediately gain market shares." pv

> *"Starting from 2026, EGP is also planning to launch even more efficient solar modules based on tandem silicon-perovskite cells"*

The evolution of solar technology: 3Sun Gigafactory

A route of innovation and sustainability

2011

Thin-film technology

- Module efficiency: capacity of converting sunlight into electricity ≈ 10%
- Monofacial module
- 25-year lifespan

About 7 million thin-film modules produced in 3Sun between 2011 and 2017

2017

Bifacial modules

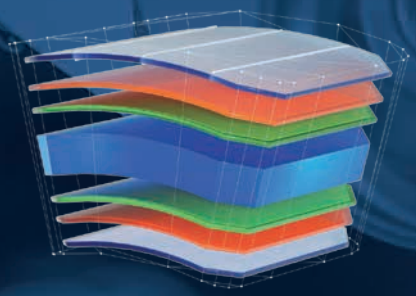
- Capable of capturing light from both sides, they produce +15% energy compared to monofacial modules
- Increased robustness against harsh environment
- 30-year lifespan

2019

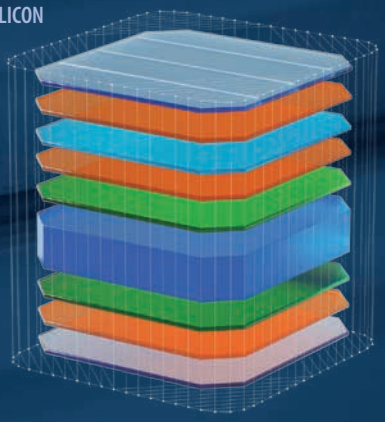
Heterojunction technology (HJT)

- 20% module efficiency, double that of the thin-film module
- The HJT technology associated with bifaciality allows for higher performance and greater energy production
- Increased useof recyclable materials
- 35-year lifespan

In 2019 3Sun launched the first European industrial line for HJT cells and modules manufacturing



- METAL GRID
- TRANSPARENT CONDUCTIVE OXIDE
- PEROVSKITE: CAN CAPTURE THE BLUE LIGHT OF THE SOLAR SPECTRUM
- AMORPHOUS SILICON
- CRYSTALLINE SILICON: USES THE RED LIGHT OF THE SOLAR SPECTRUM



2020

Two records in the same year

- Heterojunction solar cells broke the world record for commercial cells with an efficiency of 24.63%
- Achieved the 25% record of efficiency and the 95% record of bifaciality in laboratory
- The cells prove to have very high flexibility and mechanical resistance

2022 to 2024

HJT technology on large cells

- Incremental research and development to reach up to 23% module efficiency
- Silicon wafer size increased by 80%
- Fully integrated materials traceability
- Higher production processes efficiency

2025

Tandem technology

- Module efficiency above 28%
- The use of perovskite, in tandem with silicon and bifaciality, will ensure an efficiency never achieved before
- Increasingly sustainable technology: CO_2 reduction; waste reduction; reuse of modules at the end of their life
- 35-year lifespan

Two solar cell techs are

Enel Green Power has decided to develop its photovoltaic panels with crystalline solar cells based on heterojunction (HJT) architecture. HJT is a technology that, since its beginnings decades ago, has shown the potential for very high energy yields. Today, thanks to cost improvements along the entire supply chain, HJT is set to play a big part in the solar industry's future.

A closer look at Enel Green Power's HJT cell technology reveals several advantages that are set to keep the approach producing high performance solar modules for years to come.

HJT technology was pioneered by Japanese electronics company Sanyo some 25 years ago and was later acquired by Panasonic. In 2010, patents protecting Panasonic's technology expired, opening the way for PV production equipment providers and panel manufacturers to begin working on large-scale HJT manufacturing techniques. By then, these solar cells were regarded as a mature technology, but still failed to compete on cost with c-Si solar modules based on passivated emitter and rear cell (PERC) design, which remains dominant in the industry to date.

Filling the gap

The price gap depended primarily on the higher cost of the n-type wafers. These come with higher efficiency potential than the p-type products commonly used in PERC panels, but also higher cost. Another issue was the challenge of building a HJT panel factory from scratch. Other n-type technologies like tunnel oxide passivated contact (TOPCon) or interdigitated back-contacted (IBC) can be produced on converted PERC production lines, which has allowed established players to quickly ramp up new capac-

Photo: Enel Green Power

better than one!

ity. HJT, in contrast, requires an all-new production line and a different set of processes. Strong technological knowhow from quality partners is needed to implement some of these highly sensitive processes, and big production capacities are necessary to achieve economies of scale and further reduce production costs.

Most of these challenges, as of today, appear to have been solved. Several manufacturers have taken the required steps to set up GW-sized HJT factories, including Enel Green Power in Italy. Moreover, n-type wafers became cheaper in recent years and are now being gradually adopted by the entire PV industry, including PERC panel makers who are switching to produce TOPCon or IBC. And with this progress has come further improvements to HJT cell technology itself, in terms of efficiency, material consumption and sustainability.

Simpler manufacturing

HJT cell architecture involves depositing two very thin amorphous silicon (a-Si) layers, one intrinsic and one doped, onto both sides of the c-Si wafer. The first intrinsic a-Si layer passivates the c-Si, a key factor in achieving high performance. While the doped layers create the p-n device structure, which creates the bond between the high-bandgap of a-Si and the low-bandgap of c-Si, thus enabling the cell to absorb a wider segment of the solar spectrum.

A transparent conductive oxide layer (TCO) is then deposited onto the a-Si, and serves as an electrode to transport the charge generated out of the cell. Depositing the TCO layer has been a key challenge in HJT production, due to the sensitivity of the a-Si layer: the process temperature must not exceed 200 degrees Celsius, while combining best optical and electrical film properties.

While the individual steps can be quite delicate, HJT production involves fewer process steps than other silicon cell technologies. And in addition to higher efficiency, HJT cells also offer better performance at raised temperatures. And at module level, increasing use of polyolefin (POE) rather than ethylene vinyl acetate (EVA) as an encapsulant, often in combination with a glass-glass structure, means the HJT modules are particularly suitable for use in very humid and hot climates.

Lower degradation

HJT cells have already achieved efficiencies above 26% in the laboratory, and several industrial players are convinced that similar efficiency levels may soon be achievable in commercial production. Furthermore, these devices have high open-circuit voltage levels, providing better performance in hot conditions. The temperature coefficient describes the percentage of power yield that is lost by a solar cell as the temperature rises above 25 degrees Celsius. HJT has a lower temperature coefficient than PERC, meaning that these cells degrade less when exposed to higher temperature conditions over time, ensuring a higher power yield over the entire lifecycle of a PV installation.

A further long-term advantage for HJT compared to other cell types is that it apparently suffers less from two typical degradation mechanisms observed in PV cells – light-induced degradation (LID) and light and elevated temperature-induced degradation (LETID). There is still more work needed to verify these claims and to fully understand the mechanisms at work inside an HJT cell, and the track record of these newer HJT cells is, so far, limited. However, it is generally accepted that these cells are much less susceptible. This is already reflected in module performance warranties.

To go into more detail, LID in PERC cells is commonly attributed to boron-oxygen complexes that form when the cell is exposed to light. And since boron is not used to dope HJT cells, the mechanism is not present. LETID, meanwhile, is reportedly linked to rapid cooling steps in the production process. And since all processing of HJT cells must be kept at lower temperatures to avoid damaging the a-Si layer, rapid cooling steps are not used in HJT. There may, however, be other mechanisms at work affecting the performance of HJT cells over time, and work is ongoing to identify and mitigate these.

"HJT has a lower temperature coefficient than PERC, meaning that these cells degrade less when exposed to higher temperature conditions over time, ensuring a higher power yield over the entire lifecycle of a PV installation"

Innovation and sustainability in the driving seat

Enel Green Power is creating a supply chain ecosystem for its 3 GW Catania plant involving European and US partners. It will focus on two key areas to advance sustainability: using the factory's raw material inputs to create demand for sustainable silicon and wafers, and redesigning its products to increasingly move towards a circular economy approach.

In its cell and module business, Enel Green Power is approaching innovation on three fronts: using copper instead of silver, plastic instead of glass, and defining the right perovskite for tandem PV technology. "Materials innovation means being able to move toward more efficient and sustainable solutions. Materials substitution could mean that these materials are derived from recycling processes," says Nicola Rossi, head of innovation at Enel Green Power.

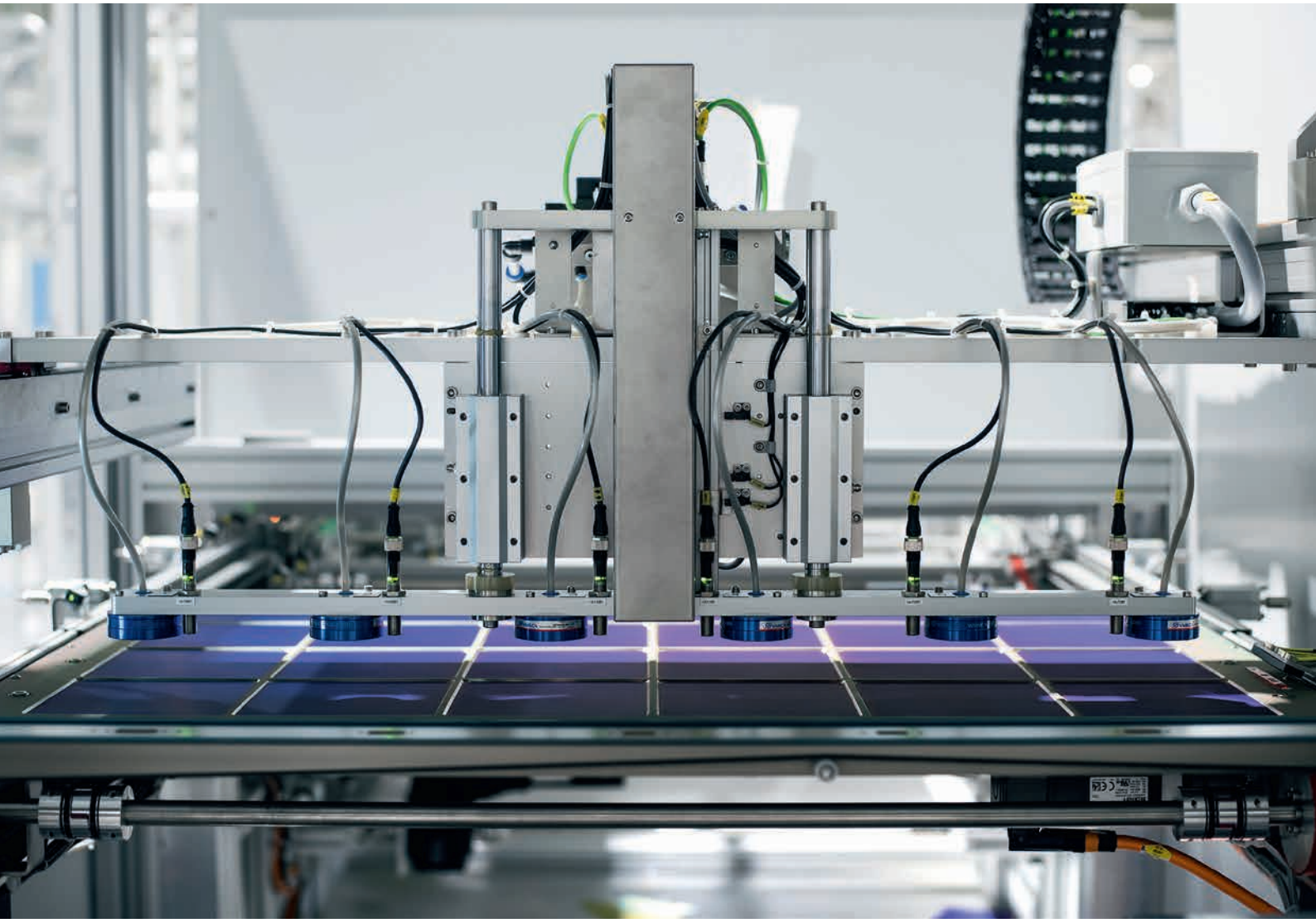
"Enel Green Power is approaching innovation on three fronts: using copper instead of silver, plastic instead of glass, and defining the right perovskite for tandem PV technology"

The first two points have to do with the promotion of a circular economy approach, which is now one of the company's main technological targets. "We are working on replacing glass with recycled and recyclable plastics that today go to landfill. The benefit is twofold: through circularity we reduce the cost, and at the same time promote supply chain diversification. It is true that glass is normally recycled, but panel glass is not normally re-used to make panels. Instead of the current down-scaling process, we want to push technological boundaries and allow up-scaling. We are now redesigning our products according to this substitution mentality. Same for copper, a material that is widely recycled and is much cheaper than the silver today used for cell metallization" says Rossi.

Enel Green Power wants to increase the efficiency of its panels from almost 24% to 30% by 2025, when it expects to begin producing perovskite-silicon tandem devices. "We want to use perovskite, but that is one class of material. We are choosing the right perovskite configuration and the best way to interface it with the bottom silicon cell in order to reach expected performance and reliability on large area and at industrial manufacturing scale. This is our challenge now," says Rossi.

The Catania factory sees a second set of advantages stemming from the highest sustainability criteria: the industry recognizes a premium for more environmentally friendly and sustainable products. "There are some virtuous countries in this regard, but there is a lack of a systematic approach, a European approach," says Rossi. "We need to develop European standards that are then implemented at the national level. We have a competitive and technological advantage, but we lack the scale, and the window of opportunity is now. We expect these actions to happen in the short term."

Photos: Enel Green Power



Enel Green Power is integrating sophisticated inspection equipment to carefully monitor processes, energy consumption and other factors.

HJT X-factor

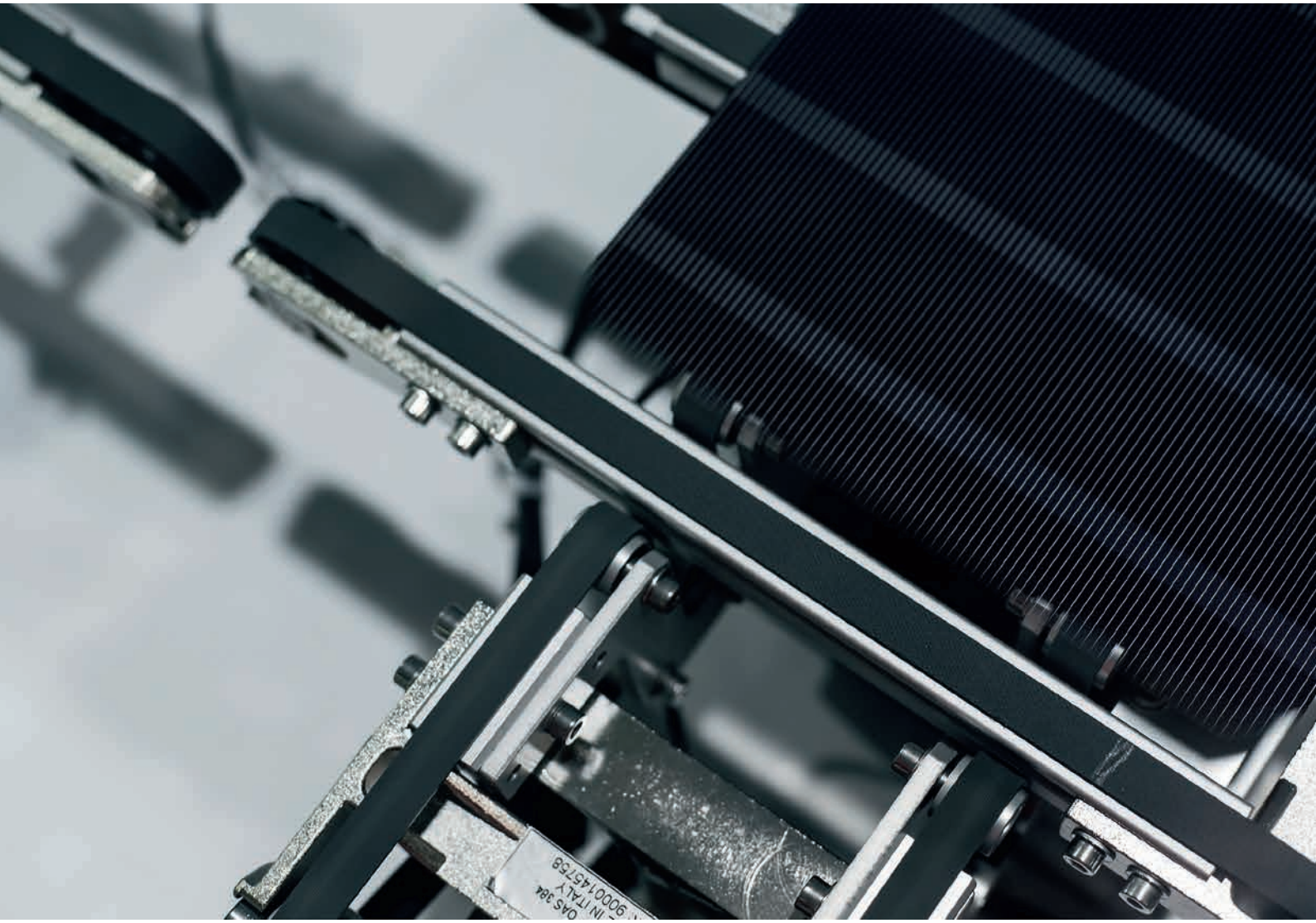
Enel Green Power started its investment in heterojunction in 2017. Back then, apart from Panasonic's previous experience, the limited heterojunction expertise in the market forced the company to open a prototype factory. At this facility it developed its algorithms, streamlined processes, and engineered the automation process. This effort resulted in a first-mover advantage.

"The heterojunction technology allows us to push automation to the maximum, in line with what is happening in the semiconductor sector. From a technological point of view, our production process is highly automated, like few others in the world," says Cosimo Gerardi, head of innovability, 3Sun Gigafactory. "The processes are done at a low temperature, less than 200 degrees, allowing the wafers to undergo very low thermo-mechanical stress. There is no handling by the operator. The wafer cannot be contaminated."

The company already deploys photoluminescence and electroluminescence analysis in the existing factory and plans to increasingly deploy these automated techniques to monitor its processes and product quality. The manufacturing process includes a series of digital control systems and sensors that give the workforce an overview of the evolution of energy consumption, singling out glitches in production. The assembly process follows a similar approach. "We are pushing more and more for automated inspections with increasingly sophisticated AI based image recognition systems," said Gerardi.

Life cycle assessment

Enel Green Power is carrying out a life cycle assessment study for its gigafactory to evaluate the carbon footprint and all other environmental and social indicators. "The assessment will be updated according to data provided by the sup-



The silver used in cell metallization is among the rarest and most costly materials in the whole process. Enel Green Power is investigating the use of copper as an alternative.

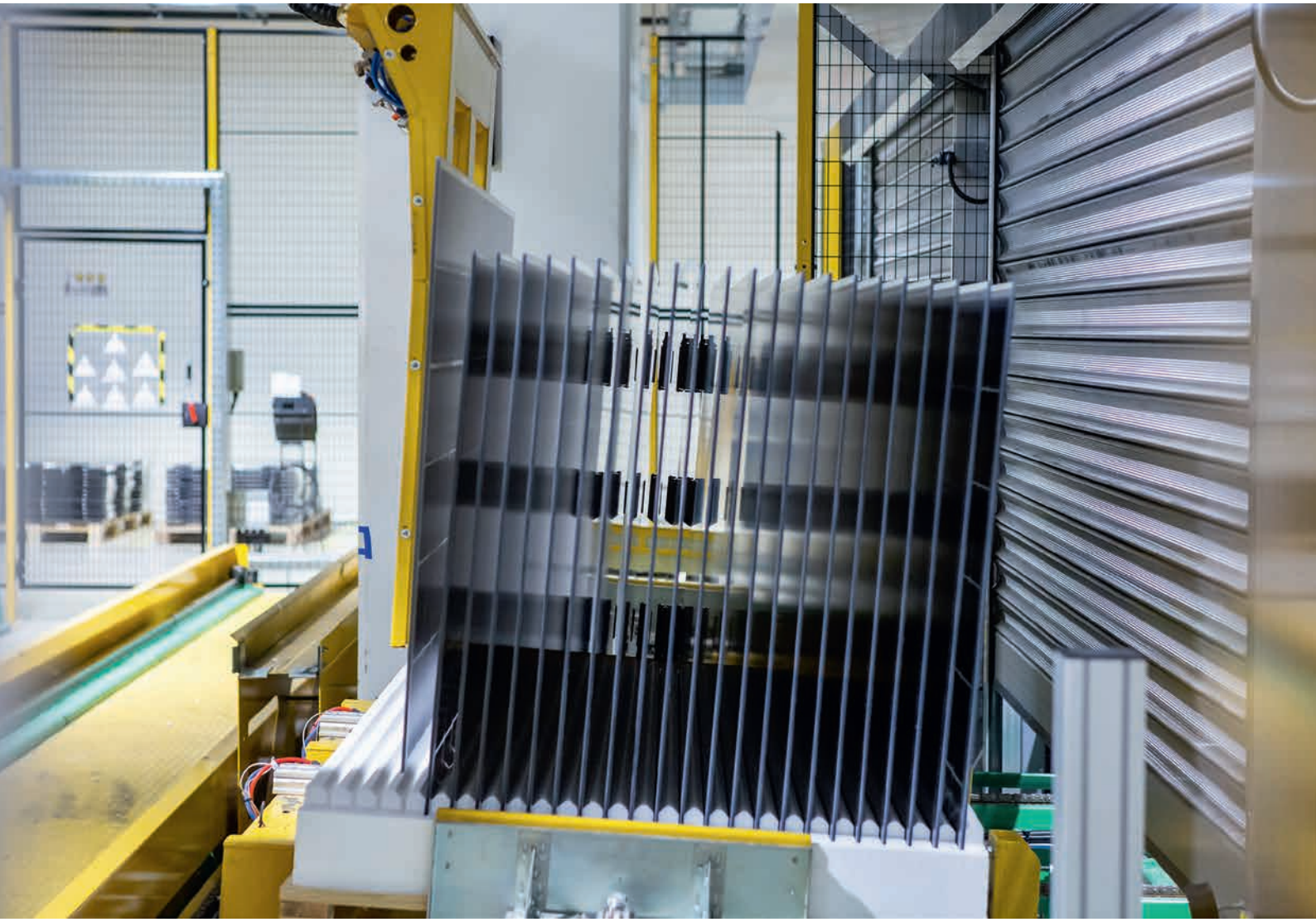
pliers by 2023. From the start of factory operation we will monitor factory data for a 12-month period, which will lead to the panel's EPD (Environmental Product Declaration) certification," says Andrea Tecci, innovation and sustainability - circular economy at Enel Green Power. Moreover, it will develop a tool to conduct sensitivity analysis internally so that the management can see how environmental indicators change as a function of different suppliers. The next step will be to promote a local production network to further align with the ongoing best practices.

"We are also initiating a series of environmental symbiosis studies. We want to attract other companies so that our inputs can be the outputs of other industries, and our outputs can be used by other companies' production processes," says Tecci.

Procurement

Enel Green Power is also working on its mid-to long-term supply chain. The company promotes and participates in association initiatives, such as the Global Alliance for Sustainable Energy. It is trying to be a catalyst for coherent initiatives increasing the traceability and sustainability of all components, possibly in collaboration with other companies. "We want life cycle assessment based certifications to become a tool through which we evaluate procurement choices, to define our supply chain," explains Giovanni Tula, head of sustainability at Enel Green Power.

The company currently requires a sustainability assessment for each supplier, selecting only those that can trace the origin of their products. "We are moving toward a series of certifications for the product and infrastructure in order to meet the highest sustainability stan-



The company is working on new module designs to maximize use of recycled materials, including potentially replacing glass with plastic on both sides of the module.

dards. The certifications will then include assessments of best practices in the operation of the factory and personnel well-being. ESG certifications in short," says Federico Barbera, head of procurement 3Sun Gigafactory. The manufacturer's officials explain that the high-quality silicon required for their wafers pushes it towards a deeper supplier selection process based on technical and sustainability criteria. The final aim is to restore the European supply chain, collaborating with national and European institutions to support actions required to materialize this shared EU vision.

Recycling

Recycling is the last strategic pillar. Enel Green Power believes that the idea of old panels going directly to landfills "is profoundly wrong," with recycling of most of the panel highly possible even today. "A solar panel, including the one that will come out of the 3Sun factory, is already between 80 and 90 percent recyclable by weight," said Nicola Rossi.

The next step will be to achieve 100% recycling, focusing first on the most valuable materials and components. "We are working on recycling silver pastes in the manufacturing process and decreasing the use of silver by introducing new designs and materials," said Gerardi.

The company offers its Italian clients an additional service: buyers can register the panels on a portal, requesting a pickup at the end of their lives at no cost. The service does not require additional investment by Enel Green Power in the short term, as the target clients will be big developers of utility-scale installations. The accumulated logistic expertise will come in handy in the future as the company increasingly targets the distributed generation market.

Innovation at scale

Enel Green Power has worked closely with French research institute CEA-Ines on qualifying materials, optimizing processes, and developing innovative technologies to be scaled up and put into use at its production lines in Catania. pv magazine met with Anis Jouini, head of solar technologies at French Alternative Energies and Atomic Energy Commission (CEA/Liten) and general director of national solar energy institute INES, to discuss the close partnership.

"We are not making a batch of 25 cells and picking all the best ones then saying listen, this is our record. It's really about proving this works at a rate of thousands of cells per hour"

CEA-Ines and Enel Green Power have worked together on high efficiency PV for a few years now – can you tell us about the partnership and its achievements?

For me, it's a story of true love which started seven years ago. Back then, we were really one of the few early adopters of heterojunction technology (HJT) worldwide. There is the historical player which is Sanyo, Panasonic, of course, but we were very active on it in terms of research and development. So now HJT is almost 15 years in development at our institute.

In the past we had partnered on this research with equipment suppliers, and we felt we were missing the third corner of the triangle – the party that will actually use this technology. We started an open collaboration with Enel Green Power (EGP), thinking about strategy and innovation together, and developing a common road map.

And this partnership has resulted in a few efficiency records in the lab – how are these confirmed and scaled up to the manufacturing environment?

We have a very strong team on both sides, and we have an industrial pilot line which goes to 100 MW, or 2,400 wafers per hour. Our approach is step-by-step development. While playing with the pyramids at the top of the wafer, or on the cell metallization, or the deposition of both amorphous silicon and the transparent conductive oxide, we find something that works. Then we go through what we call a "marathon test," where we work three days in a row stressing the tools and materials. And if that goes well, we stamp it. We say: this is real data, and it can be transferred to EGP.

In Catania they have similar tools, so the transfer and optimization for technology in industrial production is quite smooth and the people know each other closely. So, what we have is quite different from other institutes. We are not making a batch of 25 cells and picking all the best ones then saying listen, this is our record. It's really about proving this works at a rate of thousands of cells per hour.

Are these developments that you've come up with being adopted in commercial module production?

Absolutely, both in new research and in bill of materials testing and some other areas. Preparing a bill of materials and selecting components I would say is 95% down to Enel. And when they get them, they send them to us for qualification and testing based on the IEC guidelines. So, we are not a certification organization, but we are running those same tests. We can call it a kind of pre-certification.

We were having a lot of discussion of the materials that will be really used and of course the module design. Today, EGP is targeting two types of modules, one for large power plants and one for distributed generation projects.

We define the correct, or the adapted, bill of materials to get the module made with features and specifications for each market. It also gives us a reference for each module. Let's say Enel switches glass suppliers at some point: we don't have to reproduce all the tests, only some.

We do this for a few reasons. First, to compare different suppliers and components at different price points. Second, EGP is looking to secure the value chain of all products from reliable sources, and local ones wherever possible. And establishing the EGP factory is a move toward securing these supply chains in Europe.

This is a global approach to secure different components and for us, it's good. But from a technical point of view, if you change a component then you must certify the whole product again. It's progressive work, from one step to the next, with a lot of learning. We are really happy that with EGP we have this long-term partnership and open mode of collaboration.

Would it be accurate to say CEA-Ines has almost taken on the role of a quality auditor for Enel Green Power?

We are pushing much harder than that. We try to find the limit of a material. And this is very important. This cannot be done at the production line.

This takes a lot of time, and you need to push it. It goes to the deepest level with advanced tools for characterization, using microscopy to trace the cause of a failure, work out how we can recover it, and why we will choose material A and not material B.

Recently CEA-Ines also set a new efficiency record for a p-type heterojunction cell, is this something we will see with EGP?

We look at p-type from the point of view of the wafer market – there are a lot of p-type wafers available today compared to n-type, though the market is starting to shift. It was important to show that the technology can be adapted to p-type.

But along with EGP, we bet on n-type wafer more than seven years ago, and we are happy to say we have shown the way and now everybody is moving to n-type. It's taking a larger market share each year and prices are coming down as well.

And you have published work on perovskite-silicon tandem cells as well, is that the next step for the PV industry?

A lot of institutes are getting close to, or even beyond, the 30% efficiency mark with two terminal tandem cells. But they are typically working with devices measuring just a few millimeters. So, we took a different approach here as well, and began working directly on 9 cm^2 devices, and on going from this size up to 182 mm or 210 mm wafers.

Last year we got close to 25% efficiency – very symbolic because we have reached beyond what's normally achieved with HJT alone.

Photo: Enel Green Power

Anis Jouini (left) with Enel Green Power's Cosimi Gerardi showed off the heterojunction modules produced at the Catania factory during the WCPEC conference held in Milan, in September 2022.

Final thought

Keeping on the sunny side

Salvatore Bernabei, CEO of Enel Green Power

Photo: Enel Green Power

"This is the wave we are creating. The Etna Valley Gigafactory will be our forerunner, a replicable model that Enel Green Power is looking to apply elsewhere"

We have arrived at the end of this journey across the gigafactory project: we walked, step by step, through the words of our colleagues, across a history that digs its roots far in time, but a history always renewed, through innovation and adaption to changing times, contexts and market scenarios.

Looking back at the past three years, they could be described as an almost perfect storm: triggered by a global pandemic that locked down entire nations, and an overheated supply chain that wsa finally choked by raw materials scarcity and logistics bottlenecks. And now a war has burst out within Europe's borders, sparking an energy crisis that has spread around the globe.

We learned, the hard way, that energy dependence implies bigger risks than we thought and increases energy-price volatility. We need to become free; that means building a sustainable energy system. This is the right way to support and boost Europe's growth: developing more and more sustainable renewable energy capacity while also reshoring supply chains at the regional level.

The future

Today, 3Sun leaves the past behind to become something new and innovative. Enel Green Power decided to invest in the factory, transforming it into a leading European sustainable PV manufacturing operation, the largest on the continent: we are the first in Europe, intending to act as a catalyst to foster reshoring of a solar industry that can serve the whole continent.

This massive investment will boost production at 3Sun by a factor of 15 (from 200 MW to 3 GW annual output), while continuing to innovate and improve technology for a premium offering of products to the market, aiming to push module efficiency to new heights, all while creating quality onshore jobs.

Such a big change is the result of the commitment and the efforts of our people. They believed in it and worked for it to become a reality. They deemed innovation and sustainability were possible together, and successfully strived for this. They understood and proved that shared value creation is possible in Europe. This means supporting local smaller companies, such as suppliers and installers, creating quality green jobs all along the reshored supply chain: 1,000 direct jobs and as many indirect, creating opportunities for local people and specialized skills attracted from other countries.

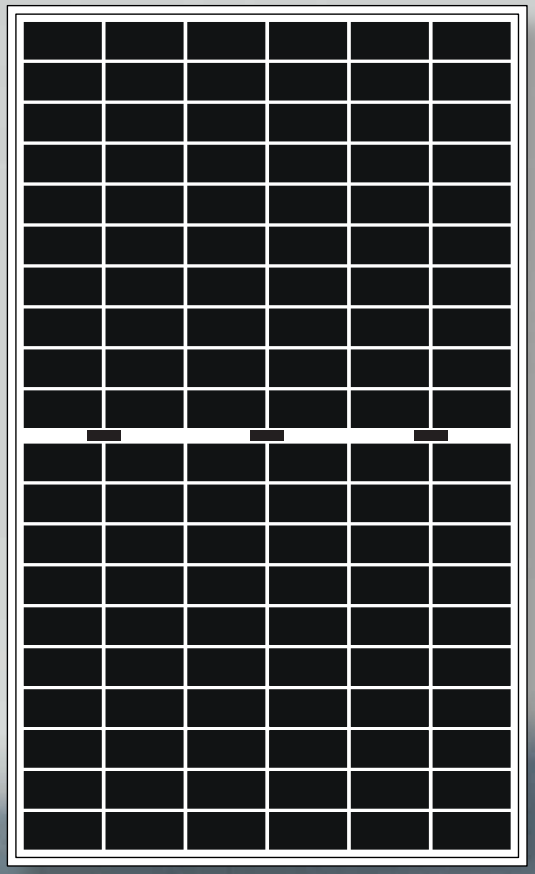
Yes, this is happening in southern Italy, giving to Sicily – our southernmost island, where Catania sits – a brand new face. On the slopes of Mount Etna, an entire innovation ecosystem is growing, warming up its engines with our gigafactory as a driver: it's what is being named our "Etna Valley". Maybe another (beneficial) "volcano" is heating up there?

This is the wave we are creating. The Etna Valley Gigafactory will be our forerunner, a replicable model that Enel is looking to apply elsewhere, such as the US. This is our next move on a challenging and exciting path, and I can say confidently that it will not be the last.

We are proud to lead the energy transition, to push ahead on this challenge. We have the soul and the courage to drive forward, together with all our people and all those willing to join with us and move fast. pv

Enel Green Power, 3Sun HJT modules technical characteristics

Dual-glass and glass-backsheet modules with best-in-class performance for different applications

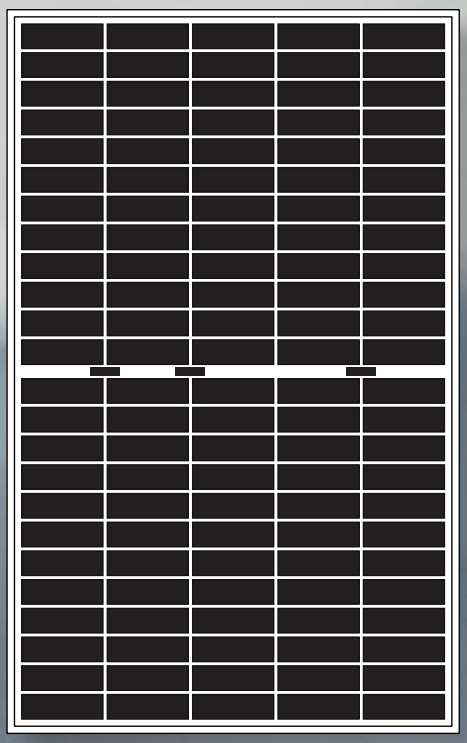


Glass-glass with frame
60 G12 cells multi busbar half cut
Module area 2.83 m² (2.172 m × 1.303 m)

Pmpp	650 W
Bifaciality factor	95% +/– 5%
Pmpp temperature coefficient	– 0.24 % / °C
First-year power degradation	1%
Annual degradation	**0.25%**

Glass-backsheet with frame
40 G12 cells multi busbar 1/3 cut
Module area 1.92 m² (1.754 m × 1.096 m)

Pmpp	460 W
Pmpp temperature coefficient	– 0.24 % / °C
First-year power degradation	1%
Annual degradation	**0.25%**



Enel Green Power, 3Sun HJT module certifications

Comprehensive third-party assessment to ensure certified quality

3Sun HJT PV module main certifications, including the standards required for product qualification, as well as additional certifications of durability under harsh environmental conditions.

CERTIFICATION	DESCRIPTION
IEC 61215:2016	Design qualification and type approval
IEC 61730:2016	Module safety qualification
UL61730-1,2 :2017	UL Standard for Safety Photovoltaic (PV) Module Safety Qualification
IEC 62716:2013	Ammonia and corrosion
IEC 60068-2-68:1996	Dust and sand
IEC 62804-1:2015	PID Degradation
IEC 62782:2016	Dynamic load test

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Green Power

We can grow with more sustainable power.

Our wind, hydro, geothermal and solar power plants have transformed the way we produce energy, energy that comes from nature, directly into our homes. All thanks to sustainable technologies and solutions.
A commitment that has enabled us to become a world leader in renewable energy, with the goal of tripling our capacity by 2030.

Choose a better tomorrow.