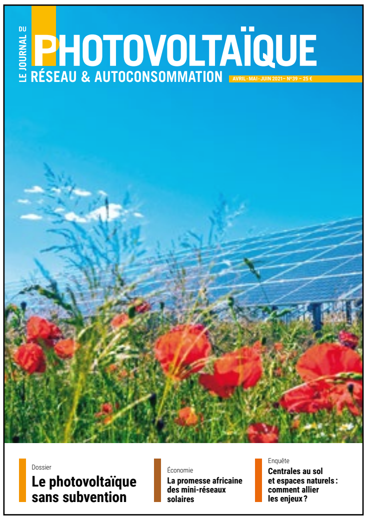
OBSERV'ER PERSPECTIVES #1

SEPTEMBRE 2021

Research and industry

PV Made in France

Observ'ER – renewables under the microscope for 40 years



The Observatoire des Énergies Renouvelables (Observ'ER) was founded in 1980, as a Paris-based independent, not-for-profit association seeking to promote renewable energies. For over 40 years, Observ'ER has steadfastly monitored and supported renewable energies' development in France and Europe, dividing its work into two main areas.

Firstly, it conducts economic surveys, tracking developments in the various renewable sectors. This research, carried out in partnership with organizations including Ademe, the FNCCR (French National Federation of Local Public Service Authorities) and the European Commission, delves into many aspects – policy implementation, the various stakeholders – and assesses the energy and economic indicators. The vast majority of Observ'ER studies are freely available for consultation on its website and those of its partners.

Observ'ER has produced a barometer that examines the French renewable electricity-generating sectors with particular emphasis on regional dynamics for over a decade. In 1999, Observ'ER launched the EurObserv'ER consortium which it has coordinated since the venture's outset. The Europe-wide programme, which has just committed to a new contract with the European Commission for 2021-2025, has earned a reputation for the production and circulation of bimonthly and annual thematic barometers. The latter analyses the progress made by all the renewable sectors, especially with regard to the Member State's commitments as borne out by their response to the European renewable energy directives. Observ'ER can count on a broad network of contacts for this work – companies, energy agencies, national statistics offices, ministries, European and national professional bodies, and so on. Over 145 thematic barometers and 20 annual barometers have been coordinated since the start of the EurObserv'ER programme. Their English versions can be read online in English at www. eurobserv-er.org.

Secondly, Observ'ER operates as a publisher, producing three quarterly magazines: *Le Journal des énergies renouvelables*, *Le Journal de l'éolien* and *Le Journal du photovoltaïque*. The first of these three was known by a different title, *Systèmes Solaires*, when it was first published in the early 1980s. Two magazines dedicated to wind energy and solar energy were created in 2007 and 2009 respectively. The association also publishes three monthly newsletters, *Les Clés de la Transition Énergétique*, with the aim of promoting energy transition initiatives to three different readership groups – local authorities, farmers and small and medium enterprises. Observ'ER also produces several brochures and longer informative guides to increase understanding of renewable energies.

Observ'ER has become a point of reference in France and Europe for decision-makers, manufacturers, journalists, research bodies, as well as environmental associations thanks to its activities and track record. Furthermore, the association has close ties with Fondation Énergies pour le Monde, set up in 1990 and recognized as a public utility organisation, which facilitates the electrification of Africa's, Asia's and South America's decentralized rural areas using renewable energy sources.

The rising sun

– Vincent Jacques le Seigneur, *Head of Publication*

Fifteen years… is that all? The history of photovoltaics certainly goes back much further because we have just celebrated the bicentenary of the birth of Becquerel, the sector's illustrious spiritual and learned father. But as Pierre Verlinden, one of the sector's experts rightly points out, "*Edmond Becquerel had no idea that his discovery would be used to power the whole planet*"… and with good reason. It takes many more building blocks to move on from making a scientific discovery to the emergence of an industrial sector. Human and financial resources, changing perceptions and mindsets and above all a shared, committed vision of energy transition have to be harnessed to ensure that the electrons generated through the sun are not commandeered for niche applications such as space exploration, connected objects and so on.

Fifteen years and counting, but the must-attend gathering for all the sector's players, the 39th, yes the 39th PV SEC conference on photovoltaics research and development, is being held. The big difference is that when the first conference took place in Luxembourg in 1977, under the auspices of the European Commission, the speakers and delegates discussed nothing but scientific research. Nobody gave a thought to an industrial sector, and that makes all the difference.

Fifteen years have elapsed since an industry emerged in Europe – primarily in France – only to evaporate almost entirely to Asia. However, technical and scientific expertise are well and truly at their pinnacle in the Old Continent and the sector has grown out of its adolescence. It is sufficiently mature to relocate its factories in Europe to satisfy growing demand with increasingly high-performance and competitive products, at the same time creating tens of thousands of jobs.

While silicon modules have become mass products that come with a 30-year plus guarantee and that can now be purchased from major retail chains, photovoltaic is hurtling headlong on its path offering growing efficiency and breakthrough technologies. To take a long-term view, it will become a resource that is as universal in the way it is used as it is to its users.

Today research is abuzz with heterojunction cells and perovskite. Their exceptional properties offer excellent prospects in conjunction with the very promising tandem cell technology that could achieve 30% efficiency, or polymer-based flexible modules that can be used on any surface, particularly in building, transport or the internet of things, and come in all the rainbow's colours. Researchers are also heavily involved in the areas of module and system quality and reliability, their integration, and resource economy and the environmental impacts, particularly of carbon…

There is no question that the key to the success of this emerging sector will have been the alliance objective established between the research laboratories after some inevitable parochial squabbles but also, and more to the point, between research and manufacturing that enable them to feed off one another. The public authorities – the European Commission, the national governments and even the local authorities – have played ball by providing substantial resources to enable the sector to scale up. Now these very same authorities need to understand that their support for the renaissance of a European photovoltaic industry is vital to rise to THE challenge of the century – climate change. We need to move faster to increase installed capacity levels every year and go further with the recovery plans if we want to be sure that the effort made will benefit of our country's economy and the men and women who live here.

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Contents

8th WORLD CONFERENCE ON PHOTOVOLTAIC ENERGY CONVERSION

SAVE THE DATE

26 – 30 September 2022
Milano Convention Centre · Milan · Italy

The WCPEC combines the three largest and most prominent international PV conferences:
the European PV Solar Energy Conference (EU PVSEC), the Photovoltaic Specialists Conference (IEEE PVSC) and the International PV Science and Engineering Conference (PVSEC).

The EU PVSEC is proud to have the World Conference back in Europe and host the 8th edition of this event, bringing together the global PV community in the beautiful city of Milan. We want to invite you to come and join us at this year's truly global event.

EU PVSEC
European Photovoltaic Solar Energy Conference and Exhibition

PVSEC
International PV Science and Engineering Conference

IEEE PVSC
IEEE Photovoltaic Specialists Conference

(Re)birth of the French PV industry

The photovoltaic industry players are gearing up to build plants in Europe, with gigafactory projects emerging and being delivered in various countries, buoyed by market momentum, particularly in France.

BY GÉRALDINE HOUOT

^ *In 2021, the French market finally woke up and took installations past the one GW mark – a first since 2012. This year the market will settle between 2 and 3 GW.*

The photovoltaic market in Europe stood at 18.2 GW in 2020. Solar Power Europe forecasts that it should pass the 20 GW mark in 2021 and continue to increase, reaching 30–40 GW p.a. in 2024. Yet, the European photovoltaic industry is stagnating. In 2020, Asian manufacturers accounted for 95% of global silicon photovoltaic module output, compared to Europe, whose share of global production was only about 3%, according to IHS Markit. Be that as it may, changes are afoot. A few manufacturers have recently commissioned or plan to build photovoltaic gigafactories to produce modules on the Old Continent, that will compete on price with their Asian counterparts. For instance, 3Sun, a subsidiary of Italy's Enel Green Power, opened a 200-MW capacity heterojunction cell plant in Catania, Sicily in 2019, that should ramp up output to 3 GW by 2024. Swiss manufacturer Meyer Burger has changed its strategy and just commissioned 400-MW capacity cell and module production lines in Germany. It aims for 7 GW of cell and 6.4 GW of module output in 2027. Other module plants


MONDRAGON ASSEMBLY


VOLTEC


RECOM SILIA

^ *From top to bottom: Mondragon Assembly PV module manufacturing production lines at Orange; the Voltec Solar module assembly shop near Strasbourg and Recom Sillia's 470-MWp plant in Brittany.*

projects are also being developed by RCT in Germany (5 GW in 2023), Ecosolifer in Hungary (2 GW) and MCPV in Portugal.

CUTTING-EDGE TECHNOLOGIES TO COMPETE WITH ASIA

All the above projects are heterojunction cell and/or module production plants. Heterojunction is an innovative technology that interfaces monocrystalline silicon and amorphous silicon. It already offers (cell) efficiency levels of almost 25%. The key to the success of Europe's plants is probably vested there, in high technology that calls for production lines that differ from those used by traditional crystalline technologies. Their operation will force Asian manufacturers to reinvest on a massive scale.

Some industrial players are already looking forward to the next move. They are banking on technologies that are even more innovative than heterojunction, such as perovskite/silicon-heterojunction tandem solar cells. At the end of July, Oxford PV completed construction of a 100-MW capacity tandem cell production plant at Brandenburg an der Havel in Germany. The efficiency of these cells is nearly 30% under laboratory conditions

IBC back-contact cells (that offer over 23% efficiency), manufactured in Europe using the process developed by the International Solar Energy Research Center Konstanz e.V. (ISC Konstanz) could also dent Chinese dominance. In any case, this is what Finland's Valoe Oyj, which started up a pilot plant in Vilnius, Lithuania at the end of 2020, is counting on.

THE FRENCH MARKET IS BOOMING

France has not been sidelined by the European thrust. Admittedly, the annual domestic market languished pitifully below the 1-GW mark throughout the last decade and its plodding pace is far short of what is needed to hit the French government's targets for 2023 (20.1 GW compared to the current 11 GW) and 2028 (35.1–44.0 GW). However, there are hints of a market upswing, as the 2021 first semester installation figure exceeded 1.3 GW. "*What gives us hope is the number of projects in the pipeline, that have not necessarily been given official authorization, but are in development. They amount to almost 8 GW.*" comments Jérémy Simon, Deputy General Delegate of the Syndicat des énergies renouvelables (SER), the French renewable energy trade association. *Lucas Weiss, CEO of the French panel maker Voltec Solar, a Strub group subsidiary, is equally enthusiastic. "We have been*

^ *Aerial view of the zone that will accommodate the forthcoming REC 4-GW heterojunction module plant at Hambach in Moselle.*

Several heterojunction cell and module gigafactory projects have been announced in France. They have yet to come out of the ground.

waiting for lift-off for a few years. Now all the scenarios predict a 4–5 GW annual market. The stakeholders have got into gear. The sector's developers who have come up with many projects and managed to pull them off have been hiring staff in the last few years."

Is that enough to boost a French photovoltaic industry? Perhaps. Several manufacturers that have developed high-efficiency heterojunction technologies in conjunction with the CEA-INES teams have recently indicated their interest in building panel plants in France. The Norwegian manufacturer REC Group is a case in point. It plans to construct a heterojunction photovoltaic panel plant designed to produce 4 GW per annum by 2025. The final decision was due to be announced in March, then in June, but it has been pushed back to December 2021, yet the project on the Hambach site, Lorraine, does not appear to be in jeopardy. In 2019, another manufacturer, Recom Technologies indicated its plan to set up a 1-GW capacity heterojunction cell and module production plant near Lyon, after acquiring the Sillia module assembly plant at Lannion in the Côtes-d'Armor in 2017 and making its head office there. "*We have invested several million euros in increasing the site's production capacities from 50 to 470 MW by renovating and automating the production lines. Redevelopment work was completed at the end of 2019, and we now produce PERC (Passivated Emitter and Rear Cell) panels there made up of 60 x 310-W mono- or polycrystalline cells. We intend to supplement this production with a heterojunction plant, as this is the technology of the future in Europe*", Julian Sarafyan, Sales Business Development Manager at Recom Technologies explains.

MORE SPECIFIC NICHES

Other manufacturers have decided to position themselves in the high value-added niches to capture the French and European markets. Following its spin-off from SunPower, the solar panel manufacturer Maxeon Solar Technologies, a TotalEnergies group subsidiary based in Singapore, decided to shut down its Toulouse plant and to develop the production of its lightweight, frameless, glass-free Maxeon Air photovoltaic panels in its other plant at Porcellette, in Moselle. These panels, the end result of five years of research, development and testing, are meant to be "adhered" to rooftops that are too weak to withstand the weight of standard solar installations. The company announced that "*the product was planned to become generally available in the first quarter of 2022*" in its 18 May press release. It puts the annual market for low-load rooftops in Europe alone, at upwards of 4 GW.

The Swiss solar tile manufacturer Sunstyle AG and the French developer Akuo Energy have set up a joint venture called Sunstyle International to relaunch the production of new-generation photovoltaic tiles. A production line went on stream on 20 October 2020 at the VMH Énergies panel assembler site at Châtellerault (Vienne) (see map p. 9), with an annual solar tile production goal of 1 GW by 2025.

LOW CARBON IN THE SPOTLIGHT

Another strategy espoused by the photovoltaic panel manufacturers Systovi and Voltec Solar has been to combine forces under the Belenos brand to cater for the widest possible market. As it happens, Voltec Solar based in Alsace, primarily focuses on the large facilities segment, while Systovi (a Cetih group subsidiary) is positioned on the residential and service sector segments. The latter is based near Nantes, and has developed aerovoltaic technology, comprising an aerothermal solar battery and a system that stores energy as hot water. Under the terms of the project, the two companies hope to increase their combined production capacity from the current figure of 300 MW to 1 GW in 2025 and improve their price competitiveness. "*It is important to give developers confidence in the French industry's capacities to service major orders. Hence, we invested 5 million euros in 2019 to raise our production capacity from 70 to 200 MW. At the start of the year, we were operating at full capacity*," comments Lucas Weiss, "*which augurs well for the Belenos project.*" The problem is that further investment will have to be made in the new facilities to adapt them to the market before they have been amortized. "*This year, we have spent 2.5 million euros on converting our equipment to produce bigger cells, while Systovi has invested 1.8 million euros for the same reasons. You need to invest every two years to keep up with the Asian manufacturers, which means that your sales turnover needs to be high,*" explains Lucas Weiss.

Voltec, which specializes in ecodesigned modules, with highly targeted R&D, is gladdened by the fact that the specifications for the upcoming photovoltaic tenders are geared to lower-carbon projects than before (the carbon offset eligibility threshold of photovoltaic installations is now set at 550 kg of CO2e per kW for most projects). A ministerial order should soon open the "on tap" Feed-in Tariff (by-passing the tendering system) for <500-kW installations. As it stands, it currently applies to <100-kW installations. In principle, the order should also benefit more environmentally-friendly projects (whose carbon offset eligibility threshold is also set at 550 kg CO2e per kW).

The French and European industries have not yet won the day. Firstly, because Asian manufacturers are capable of producing low-carbon solar panels which will meet the required eligibility thresholds. Furthermore, they are also banking on innovation. "*China is not behind as regards technologies. Moreover, their manufacturers have much greater investment capacities than ours do. State and European aid must be forthcoming if we are not to miss the boat*", Lucas Weiss comments. However, two years ago there was absolutely no question of any aid for the Recom Technologies heterojunction plant project in Lyon. "*Waiting for solid support and aid from the French government and the BPI in particular, came to nothing. The project has been put on hold. We refuse to give up and are still hoping that when positive changes to EU and French government policies on renewable energies are introduced, we will be able to go ahead*", comments Julian Sarafyan, who is campaigning for European Union Member State cooperation to organize competition to head off the Asian behemoths. The *European Solar Manufacturing Council* (ESMC) is examining the possible creation of an IPCEI (Important Project of Common European Interest) on photovoltaic, as it did for lithium batteries and hydrogen. "*That will not mean that we can compete with Chinese funding capacities*," comments Lucas Weiss, "*But it would narrow the gap, which would be most welcome.*" ■

The ARaymond Energies module fastening manufacturing shop at Grenoble.

PV manufacturing in France

VALUE CHAIN SEGMENTS

- Components
- Engineering services & equipment manufacturing
- Ingot
- Wafer
- Cell
- Module/Tile
- Structure
- Inverter/Electrical components
- Recycling
- Competitive cluster (see p. 10)

Warning: This map does not claim to be comprehensive. The French agency for ecological transition (Ademe) reckons, for instance, that France has about a hundred companies that manufacture electronic components or structures dedicated to solar installations. Here we aim to give an overview of France's photovoltaic value chain, and primarily what is upstream of this chain. – The companies are listed on p. 10-12.

SOURCES: OBSERV'ER, INES, CAPÉNERGIES, DERBI, TENERRDIS, S2E2

MODULE

2CA – Concept Composites Auvergne/Operasol
Technology: ultralight composite photovoltaic modules, dual glass or glass-tedlar modules, mainly monocrystalline silicon, monocrystalline heterojunction-compatible
Manufacturing capacity: 15-20 MW p.a.
Since: January 2021
Site: Arlanc (Puy-de-Dôme)
Website: www.2ca.fr – www.operasol.fr (being redesigned)

STRUCTURE

AdiWatt
Technology: roof structures, solar farms, carports
Manufacturing capacity: 700 MW p.a. (France + Spain)
Since: 2009 (French operation)
Site: Fontaine Raoul (Loir-et-Cher)
Website: www.adiwatt.com

MODULE

Akuo Energy/SunStyle
Technology: monocrystalline silicon solar tiles
Manufacturing capacity: 50 MWp (provisional: 1 GWp in 2025)
Since: 20 October 2020
Manufacturer: VMH Énergies (see below)
Site: Châtellerault (Vienne)
Website: www.akuoenergy.com

ENGINEERING SERVICES & EQUIPMENT MANUFACTURING

Alliance Concept
Technology: PVD thin layer deposition machine
Activity: 595 machines installed worldwide
Since: 1991
Site: Annecy (Haute Savoie)
Website: www.alliance-concept.com

ENGINEERING SERVICES & EQUIPMENT MANUFACTURING

Annealsys
Technology: annealing furnaces and thin layer deposition machine
Manufacturing capacity: undisclosed
Since: 2004
Site: Montpellier (Hérault)
Website: www.annealsys.com

MODULE

Apollon Solar
Technology: encapsulated photovoltaic modules using the NICE process
Manufacturing capacity: 50 MW p.a.
Since: 2001
Site: Saint-Priest (Rhône)
Website: www.apollonsolar.com

STRUCTURE

ARaymond Énergies
Technology: module and cable fastening systems for ground-based and roof-mounted solar plants
Manufacturing capacity: undisclosed
Since: 2015
Site: Grenoble (Isère) and other manufacturing plants around the world
Website: www.araymond-energies.com/en

COMPONENTS

Arkema
Technology: solar panel-specific polymers
Manufacturing capacity: undisclosed
Since: 1948
Site: Pierre-Bénite (Rhône)
Website: www.arkema.com/france/en/locations/r-and-d-centers/pierre-benite-crra

CELL/MODULE

Armor solar power films
Technology: organic cells/modules
Manufacturing capacity: 1 million m² p.a.
Since: 2016
Site: La Chevrolière (Loire-Atlantique)
Website: www.asca.com

INVERTER

AXID
Technology: inverter, turnkey inverter plant projects
Manufacturing capacity: undisclosed
Since: undisclosed
Site: Biot (Alpes-Maritimes)
Website: www.axid-system.com

MODULE

BEEM ENERGY
Technology: PERC monocrystalline silicon plug&play PV kits
Manufacturing capacity: the modules are designed in France but manufactured in China
Since: 2020
Site: Nantes (Loire-Atlantique)
Website: www.beemenergy.com

ENGINEERING SERVICES & EQUIPMENT MANUFACTURING

Cameca
Technology: thin layer production equipment
Manufacturing capacity: undisclosed
Since: founded in 1929
Site: Gennevilliers (Hauts-de-Seine)
Website: www.cameca.com

COMPETITIVE CLUSTER

Capénergies
Activity: development and deployment of clean energy systems
Since: 2005
Site: Aix-en-Provence
Website: www.capenergies.fr

INVERTER

Cefem Solar
Technology: inverter
Manufacturing capacity: undisclosed
Since: 2010
Site: Saint Michel de Boulogne (Ardèche)
Website: cefem-group.com/cefem-solar

STRUCTURE

Ciel&Terre International
Technology: high density polyethylene (HDPE) floater for floating power plants
Activity: 230 sites equipped around the world, 2 production centres in France (in undisclosed sites)
Since: 2006
Site: (Head office) Sainghin-en-Méantois (Nord)
Website: www.ciel-et-terre.net/fr

INVERTER/ ELECTRICAL COMPONENTS

CIRTEM
Technology: bidirectional and multilevel inverters
Manufacturing capacity: undisclosed
Since: undisclosed
Site: Sainte-Foy-d'Aigrefeuille (Haute-Garonne)
Website: www.cirtem.com

ENGINEERING SERVICES & EQUIPMENT MANUFACTURING

Corial
Technology: materials treatment using plasma technology
Manufacturing capacity: undisclosed
Since: 2004
Site: Bernin (Isère)
Website: corial.plasmatherm.com/en

INVERTER

Cristec industries
Technology: inverter and load regulator
Manufacturing capacity: undisclosed
Since: 1983
Site: Quimper (Finistère)
Website: www.cristec.fr

COMPETITIVE CLUSTER

Derbi
Activity: development of renewable energies in the construction sector and industry
Since: 2005
Site: Perpignan (Pyrénées-Orientales)
Website: www.pole-derbi.com

STRUCTURE

Dome Solar
Technology: module fastening systems for large roofs
Manufacturing capacity: undisclosed
Since: 2008
Site: Rezé (Loire-Atlantique)
Website: dome-solar.com

CELL/MODULE

Dracula Technologies
Technology: organic cells and modules
Manufacturing capacity: undisclosed
Since: 2017 - Pre-industrial line in 2020
Site: Valence (Drôme)
Website: dracula-technologies.com

MODULE

DualSun
Technology: monocrystalline modules and hybrid monocrystalline modules* (PVT)
Manufacturing capacity: 30 000 PVT panels p.a., about 11 MW electrical and 12 MW thermal
Inauguration: 2013 (first sales) - April 2020 (new line, to be expanded in September 2021)
Plant: Jujurieux (Ain)
Website: dualsun.com

* Only the PVT modules are manufactured in France, the photovoltaic modules (DualSun Flash range) are assembled in Asia.

COMPETITIVE CLUSTERS AT THE CROSSROADS BETWEEN INDUSTRY AND RESEARCH

Competitive clusters draw together stakeholders from different horizons with complementary profiles for the purpose of creating synergies in a region around a targeted theme. There are four renewable energy and energy transition clusters in France that all have photovoltaics as one of their focal areas. These clusters that were set up in 2005, are tasked with matching private with public research specialists, training bodies and local business networks to devise innovative products and services and bring them to market.

ENGINEERING SERVICES & EQUIPMENT MANUFACTURING

ECM GREENTECH S.A.S.
Technology: Crystalmax ingot growth furnace ("Mono Like" polycrystalline)/production lines
Activity: 1 409 low-pressure cementation furnaces installed worldwide
Since: 1970
Site: Grenoble (Isère)
Website: ecm-greentech.fr

MODULE

Edilians
Technology: monocrystalline silicon photovoltaic tile
Activity: over 9 000 houses equipped with photovoltaic tiles
Since: 2018 (formerly Imerys Toiture, set up in 2001)
Site: (Head office) Arnas (Rhône)
Website: edilians.com

STRUCTURE

Exosun - ArcelorMittal
Technology: horizontal single axis tracker
Activity: 1 GW of photovoltaic panels installed worldwide
Since: 2007
Site: Martillac (Gironde)
Website: projects.arcelormittal.com/solar/products/utility-scale-PV/language/EN

COMPONENTS/CELL/MODULE

G-Lyte
Technology: electrolytes, tinted cells and modules
Manufacturing capacity: undisclosed
Since: 2019
Site: Amiens (Somme)
Website: fr.linkedin.com/company/g-lyte

STRUCTURE

GSE Integration (Terreal Group)
Technology: building integration systems
Manufacturing capacity: undisclosed
Since: 2010
Site: Laval (Mayenne), Sablé sur Sarthe (Pays de la Loire) and Langeais (Indre-et-Loire)
Website: www.gseintegration.com/en

STRUCTURE

HeliosLite
Technology: 1.5 axis and dual axis PV tracker
Manufacturing capacity: undisclosed
Since: 2016
Site: Le Bourget du Lac (Savoie)
Website: helioslite.com

ENGINEERING SERVICES & EQUIPMENT MANUFACTURING

IBS - Ion Beam Service
Technology: cell plasma-immersion ion implantation (PIII) doping technology
Manufacturing capacity: undisclosed
Since: 2020
Site: Peynier (Bouches-du-Rhône)
Website: www.ion-beam-services.com/company/

INVERTER/ ELECTRICAL COMPONENTS

Imeon Energy
Technology: inverters
Manufacturing capacity: undisclosed
Since: 2013
Site: Brest (Finistère)
Website: imeon-energy.com

STRUCTURE

IRFTS
Technology: building integration systems for photovoltaic modules
Manufacturing capacity: 120 000 integration systems p.a.
Since: 2009
Site: Oyonnax (Ain)
Website: fr.irfts.com

STRUCTURE

LTE
Technology: 1- or 2-axis trackers for photovoltaic modules
Manufacturing capacity: undisclosed
Since: 2008
Site: Ploermel (Morbihan) Ain)
Website: www.lte-fr.com

MODULE

Maxeon Solar Technologies
Technology: since 2012 assembly of SunPower modules. In the near future: lightweight frameless glass-free monocrystalline silicon modules
Manufacturing capacity: undisclosed
Since: May 2012
Site: Porcellette (Moselle)
Website: www.sunpower.maxeon.com

STRUCTURE

MECOSUN
Technology: fastening onto bare structural frameworks, superimposition, sun shelters, greenhouses or growing sheds
Activity: 3 million m² installed
Since: 2008
Site: (Head office) Saint-Lys (Haute-Garonne)
Website: www.mecosun.fr

INVERTER/ ELECTRICAL COMPONENTS

Mersen Group
Technology: electrical components and advanced materials (such as graphite and silicon carbide)
Manufacturing capacity: undisclosed
Since: undisclosed
Site: (Head office) La Défense (Hauts-de-Seine)
Manufacturing sites: 8 in France
Website: www.mersen.com/group/mersen-group

STRUCTURE

Mitjavila
Technology: structures for photovoltaic awnings and pergolas
Activity: undisclosed
Since: Created in 1970 but developed photovoltaic ranges in 2012
Site: Rivesaltes (Pyrénées-Orientales)
Website: www.mitjavila.com

ENGINEERING SERVICES & EQUIPMENT MANUFACTURING

Mondragon Assembly
Technology: module production lines, Tabber & Stringer, Lay-out Stringers, Laminators, Framing Machines, Cell Tester & Sorter, Services
Manufacturing capacity: about € 50 M p.a.
Since: 2001
Site: Orange (Vaucluse)
Website: www.mondragon-assembly.com/fr/

STRUCTURE

Nexans Solar Technologies
Technology: single axis tracker
Manufacturing capacity: undisclosed (manufacturing in Europe and Turkey)
Since: undisclosed
Site: (Head office) La Défense (Hauts-de-Seine)
Website: www.nexans.com/business/Industry---Solutions/Solar/Nexans-Solar-Technologies.html

INVERTER

Nitram
Technology: inverter
Manufacturing capacity: undisclosed
Since: founded in 1983
Site: Cloyes (Eure-et-Loir)
Website: www.nitram.fr

STRUCTURE

Okwind
Technology: Dual axis PV tracker
Activity: more than 1 200 trackers installed since 2014
Since: 2014
Site: Torcé (Ille et Vilaine)
Website: www.okwind.fr

STRUCTURE

Ombrea
Technology: agrivoltaics, shadehouses for horticulture that may include solar modules
Activity: undisclosed
Since: 2016
Site: Aix-en-Provence (Bouches-du-Rhône)
Website: www.ombrea.fr

STRUCTURE

Optimum tracker
Technology: trackers for photovoltaic modules
Manufacturing capacity: undisclosed
Since: 2009
Site: Meyreuil (Bouches-du-Rhône)
Website: www.optimum-tracker.com

ENGINEERING SERVICES & EQUIPMENT MANUFACTURING

Pfeiffer Vacuum France
Technology: systems for vacuum generation
Manufacturing capacity: undisclosed
Since: (company founded in 1890)
Site: Annecy (Haute Savoie)
Website: group.pfeiffer-vacuum.com/en/group/corporate-profile/

INGOT/WAFER

Photowatt (EDF Renouvelables)
Technology: Crystal Advanced® Mono Like polycrystalline silicon. Originally an integrated module producer. The company refocused on ingots and wafers in 2018.
Manufacturing capacity: 200 MWp
No. of employees: 214
Since: 1984
Site: Bourgoin-Jallieu (Isère)
Website: www.photowatt.com/fr

STRUCTURE

Poralu Marine
Technology: polyethylene floater for floating PV
Manufacturing capacity: undisclosed
Since: 1999
Site: Port (Ain)
Website: www.poralu.com/pontons-et-autres-produits/flotteurs-en-polyethylene/

ENGINEERING SERVICES & EQUIPMENT MANUFACTURING

R2D Automation
Technology: wafer transfer PLC
Manufacturing capacity: undisclosed
Since: 1992
Site: Clapiers (Hérault)
Website: www.r2d-automation.com/

MODULE

Recom Sillia
Technology: poly- and monocrystalline silicon modules
Manufacturing capacity: 470 MWp
Since: 2008
Site: Lannion (Côtes-d'Armor)
Website: www.recom-sillia.com

MODULE
Reden Industries (Reden Solar)
Technology: bifacial modules
Manufacturing capacity: 65 MWp p.a.
Since: 2008
Site: Agen (Lot-et-Garonne)
Website: reden.solar/en/our-approach/manufacture-of-photovoltaic-modules/

ELECTRICAL COMPONENTS
Reyes Groupe
Technology: power converters
Manufacturing capacity: undisclosed
Since: 1974 (company founded)
Site: Valence (Drôme)
Website: www.reyesgroupe.fr

ENGINEERING SERVICES & EQUIPMENT MANUFACTURING
RIBER
Technology: Molecular-beam epitaxy (MBE) reactors for thin-film deposition
Manufacturing capacity: undisclosed
Since: undisclosed
Site: Bezons (Val d'Oise)
Website: www.riber.com

RECYCLING
Rosi Solar
Technology: kerf and photovoltaic module recycling
Manufacturing capacity: undisclosed
Since: 2018 (company founded), 2022 (plant operational)
Site: La Mûre (Isère)
Website: www.rosi-solar.com

COMPETITIVE CLUSTER
S2E2
Activity: electrical and thermal energy management
Since: 2005
Site: Tours (Indre-et-Loire)
Website: www.S2E2.fr

COMPONENTS
Saint-Gobain Quartz
Technology: Quartzel wafer for solar and semiconductors
Manufacturing capacity: undisclosed
Since: founded in 1922
Site: Nemours (Seine-et-Marne)
Website: www.quartz.saint-gobain.com

INVERTER/ ELECTRICAL COMPONENTS
Schneider
Technology: inverters, storage, micro-grids
Manufacturing capacity: undisclosed
Since: founded in 1836
Site: (Head office) Rueil Malmaison, (Hauts-de-Seine) and 10 sites in France
Website: www.se.com

ENGINEERING SERVICES & EQUIPMENT MANUFACTURING
Semco Technologies (ACM technologies group subsidiary)
Technology: technology solutions for industrial photovoltaic production processes
Activity: 300 employees and sales worth over 90 million euros
Since: 1986
Site: Montpellier (Hérault)
Website: semco-tech.com

WAFER
Sil'tronix silicon technologies
Technology: silicon wafers and thin layers
Manufacturing capacity: undisclosed
Since: 2014
Site: Archamps (Haute Savoie)
Website: www.sil-tronix-st.com/fr/accueil

ELECTRICAL COMPONENTS
Sirea Group
Technology: switchgear cabinets, automation systems, software
Manufacturing capacity: undisclosed
Since: undisclosed
Site: Castres (Tarn)
Website: www.sireagroup.com

INVERTER/ ELECTRICAL COMPONENTS
Socomec
Technology: inverter
Manufacturing capacity: undisclosed
Since: 1922
Site: Benfeld (Bas-Rhin)
Website: www.socomec.fr

CELL
SolarClothSystem
Technology: thin layer photovoltaic film
Manufacturing capacity: undisclosed
Since: 2014
Site: Mandelieu-La Napoule (Alpes-Maritimes)
Website: www.solarclothsystem.com

STRUCTURE
Solarsit
Technology: rooftop solar
Manufacturing capacity: undisclosed
Since: 2009
Site: Aytré (Charente-Maritime)
Website: www.solarsit.fr

ENGINEERING SERVICES & EQUIPMENT MANUFACTURING
Solean
Technology: module assembly solution
Manufacturing capacity: undisclosed
Since: undisclosed
Site: Le Bourget-du-Lac (Savoie)
Website: solean.fr

CELL/MODULE
Solems
Technology: amorphous silicon solar cell
Manufacturing capacity: 12 kW
Since: 1981
Usine: Palaiseau (Essonne)
Website: www.solems.com

STRUCTURE
Soprasolar
Technology: roof terrace integration systems
Manufacturing capacity: undisclosed
Since: 2008
Site: Lyon (Rhône)
Website: www.soprasolar.com

RECYCLING
Soren (formerly PV Cycle)
Technology: collection, separation, and recovery of photovoltaic materials
Activity: 15 000 tonnes collected between 2015 and 2020
Since: 2015
Site: Paris
Website: www.soren.eco

MODULE
S'Tile
Technology: mono- and polycrystalline photovoltaic tiles and double-glass modules
Manufacturing capacity: 20 MW p.a.
Since: 2017
Site: Poitiers (Vienne)
Website: silicontile.fr

STRUCTURE
Sun Integration
Technology: building-integrated structures for modules
Manufacturing capacity: undisclosed
Since: 2012
Site: Hageneau (Bas-Rhin)
Website: www.sun-integration.com

STRUCTURE
Sun'Agri
Technology: designers of agrivoltaic structures and developers of photovoltaic greenhouses
Activity: three experimental installations mounted in France
Since: 2009
Site: Paris (head office) and Lyon (Rhône – technical team)
Website: unagri.fr

MODULE
Systovi
Technology: monocrystalline modules and aerovoltaic hybrid modules + storage solutions and green energy management
Manufacturing capacity: 50 MW p.a.
Since: 2008
Site: Carquefou (Loire-Atlantique)
Website: www.systovi.com

STRUCTURE
T-solaris
Technology: building-integrated structure, with heat recovery or indoor air-conditioning system
Manufacturing capacity: 50 000 m^2 deployed
Since: undisclosed
Site: Lévignac (Haute Garonne)
Website: www.tsolaris.com

COMPETITIVE CLUSTER
Tenerrdis
Activity: improve the competitiveness of the industrial sectors of new energy technologies through innovation
Since: 2005
Site: Grenoble (Isère)
Website: www.tenerrdis.fr

ENGINEERING SERVICES & EQUIPMENT MANUFACTURING
Thermocompact
Technology: EDM wire and diamond wire saw
Manufacturing capacity: undisclosed
Since: founded in 1913
Site: Epagny-Metz-Tessy (Haute-Savoie)
Website: thermocompact.com/fr

RECYCLING
Veolia
Technology: recycling crystalline silicon modules
Processing capacity: up to 4 000 tonnes p.a.
Since: 2018
Site: Rousset (Bouches-du-Rhône)
Website: www.veolia.com/en

MODULE
VMH Énergies
Technology: monocrystalline modules and photovoltaic solar tiles
Manufacturing capacity: undisclosed
Since: 2013
Site: Châtellerault (Vienne)
Website: www.vmh-energies.com

MODULE
Voltec Solar (STRUB Group)
Technology: mono- and polycrystalline modules
Manufacturing capacity: 200 MWp
Since: 2010
Usine: Dinsheim-sur-Bruche (Bas-Rhin)
Website: www.voltec-solar.com

MODULE
Wattway (Colas)
Technology: photovoltaic road paving
Manufacturing capacity: undisclosed
Since: 2015
Site: Magny Les Hameaux (Yvelines)
Website: www.wattwaybycolas.com

Photovoltaic's amazing adventure

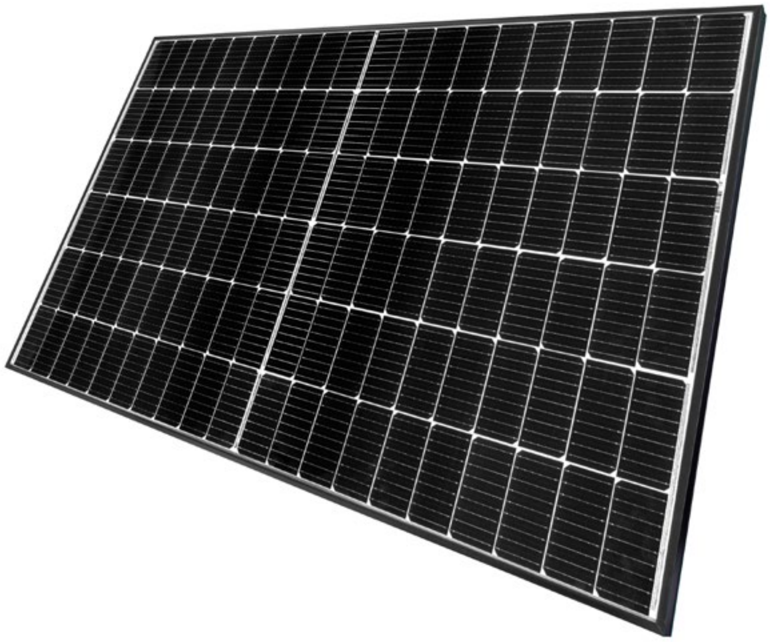
Photovoltaic energy is destined to become one of the main energy sources of the global mix. Europe must play its part in the expected meteoric industrial expansion if it is to remain energy independent. The coming years' challenges for photovoltaics are political, industrial and scientific rolled into one. It certainly has its work cut out for it.

BY VINCENT BOULANGER

^ *Power plant on trackers at Madera, California, commissioned in 2010 by REC.*

"When I joined INES 12 years ago, I was asked which technology we should bet on 5 years down the road. I answered, silicon… and in 10 years' time? Silicon", recalls Anis Jouini, Head of Solar Technologies Department at CEA-LITEN and Director General of the French National Institute for Solar Energy (INES). His forecast for today was right, as crystalline silicon technologies totally dominate the market and continue their onward march. It has to be said that the cell efficiency levels attained are now approaching the theoretical limit for monocrystalline silicon, but the race to innovate is far from over. Wafer size is increasing all the time, and in just the space of 2 years has leapt from M6 (166 mm) to M12 (210 mm) while production throughput is following the same trend. "*In 2014, the machines delivered at the rate of 1 200 cells per hour,*" Anis Jouini remembers. "*This year, there are machines coming out*

REC was the first manufacturer to introduce half-cell modules in 2015. Here, the latest REC TwinPeak 4 module.



REC GROUP

Within the next five years, we need to successfully industrialize heterojunction modules and prepare for the industrialization of tandem modules.

WEANING OURSELVES OFF SILVER

One major issue for the sector is to reduce its raw materials consumption, primarily the critical materials, such as silver. *"We need to reduce our consumption of silver by a factor of 7–10 per Wp on condition that conductive properties are the same,"* asserts Anis Jouini. *"It is technically achievable. The other way would be to substitute it with copper. We have produced heterojunction cells metallized with copper, so this is not only feasible, but comes with the performance levels. What is holding us back, is that industrial copper deposition machines suitable for photovoltaic haven't been invented yet. We must be capable of producing cells in their thousands."*

on the market that can produce 10 000 cells per hour. This pace has yet to be matched by the whole line (chemical deposition, metallization, etc.), but has increased by a factor of almost 10 over seven years." The same quest for continuous improvement applies to module design, with the advent of half-cell modules. Why on earth would we want to produce large wafers if it is only to cut them in half afterwards? "*That's what's so wild about PV,* Anis Jouini chuckles, *this industry is prepared to do anything as long as there are gains to be made.*" Cutting cells in half effectively reduces the current generated by the cell, which lowers the resistive losses and enables the module to produce more electricity.

Developments in crystalline silicon will continue, as the new, emerging generation of heterojunction modules still gravitates around it (see p. 38). European industry is trying to rebuild itself on this technology, but the try scored needs to be converted. "*We must succeed in producing large heterojunction cells offering 25% efficiency and at high throughput in the next 2 years. That, in a nutshell, is our challenge.*"

ACHIEVING INDUSTRIALIZATION

Process management is one thing but stepping up production is quite another ball-game. The real challenge is to relocate an industry with capacities running to the tens of GW in Europe. "*There are on-going attempts to reindustrialize, but they are pitched at too low a scale,*" judges Jochen Rentsch, Head of the Production Technology: Surfaces and Interfaces Department at Fraunhofer Institute for Solar Energy Systems (ISE). "*Heterojunction module lines with capacities of 200 MW or 400 MW, are small fry in the big global picture of 150 GW. We are a long way from being competitive. That's the biggest challenge and we are channelling a lot of energy into it at the moment.*" There are at least three different arguments for reinstalling the photovoltaic industry. Firstly, transport costs weigh heavily in the price of modules, so producing locally would result in a cost advantage. Next, the European carbon neutrality goals will force us to make a serious examination of the CO_2 footprint of imported products. The carbon balance of modules produced in Europe is much better on this level than those manufactured in China. Lastly, if these climate goals are taken seriously, solar energy will become an important part of the European energy mix, and manufacturing in Europe would also be a pledge of energy independence. Not to mention research: "*There are not enough industrial partners to develop new concepts,*" Jochen Rentsch regrets. "*Developing a technology in a partnership framework with a European manufacturer is worlds apart from doing it in a trade context for a customer outside Europe.*"

REINSTALLING THE ENTIRE CHAIN

The task is made even harder by the fact that not only do the cells and modules have to be produced in Europe, but the

^ *The 28-MW Dubbo Solar Hub was completed in 2018 by Neoen in Australia.*

CHEAPER ALL THE TIME. WHAT'S THE POINT?

"In the early 2000s, the NREL laboratory aimed to achieve a photovoltaic system price of $ 1 per Wp, today we are down to $ 0.1 per Wp (modules), and we could reduce this further to $ 0.05 per Wp or below. Is this really desirable?" asks Pere Roca i Cabarrocas. *"If it's in order to use an increasing amount of energy, squander it as we do now, exploit the resources and litter the planet with more and more waste, then I say no! I didn't become a researcher for that reason. On the contrary, we must change our mindsets and value energy more. The same goes for recycling. It is cheaper to create new mines and pollute the planet, than efficiently recycle what we have already extracted. That is indefensible. Recycling will have to become compulsory, and modules will have to be designed from the outset to make recycling and the recovery of their materials easy."*

entire production chain needs to be reinstalled: ingots, wafers, PV quality glass, aluminium frames, electronic units, etc. Norsun and Norwegian Crystals, Europe's last remaining ingot and wafer producers, have growth plans, but not at a scale that will satisfy the European market's needs. Jochen Rentsch explains, "*The revival of the entire chain is simply a matter of demand. If, for instance, the demand for PV glass for European modules were to be renewed, our glassmakers will reinvest in PV glass production lines.*" For that to become a reality, the European solar industry does not need subsidies so much as a change of heart by its leaders, who do not appear to have grasped what solar's future role will be in the global energy mix. Even the scenarios released by Shell, with its vested interests in oil, coal and gas, forecast that solar energy's contribution to the global energy mix will be 5–15% in 2050. The incumbent French government is still miles away from recognizing solar's future role. While it considers the energy mix of the future, it is planning to build more nuclear power plants. In actual fact, as Gaëtan Masson, Co-Chairman of the European Solar Manufacturing Council (ESMC) points out, the last decade has been marked by the European governments' efforts to thwart solar's take-off and hold it down under a lid. They should now be pulling it out of its rut and giving it a free rein.

PRODUCING MORE WITH LESS SURFACE AREA

"*If we want to achieve our climate goals, we will need to produce a lot of electricity, especially to produce hydrogen,*" Pere Roca i Cabarrocas, Scientific Director of the Île-de-France Photovoltaic Institute (IPVF) reminds us. The International Renewable Energy Agency (IRENA) has produced the "Transforming Energy Scenario" to illustrate how we can successfully keep climate warming down below 2°C, as required by the Paris Agreement. The scenario calls for a combined global photovoltaic installed capacity of 8 828 GW by 2050, compared to 708–760 GWp at the end of 2020[1] which will entail having to double the annual global market from now on. "*That means we need to increase photovoltaic's efficiency to extract more energy out of less surface, and we must also integrate photovoltaics almost everywhere, in buildings, on vehicles, and so on. Multijunction is the way forward for increasing yields… starting with tandem cells, then moving on to triple junction. A lot of work still remains to be done on their constituent materials, but when we look into the physics aspects, we know that we can achieve more than 60% efficiency, without having to resort to hot carrier cells.*" Pere Roca i Cabarrocas reckons that we need to abandon the monoculture of crystalline silicon to meet the various challenges. He considers thin film modules to be useful because of

^ *The 300-MWp photovoltaic power plant at Cestas, south of Bordeaux, was commissioned in 2015.*

Annual photovoltaic installation capacities across the world need to be doubled as of now if we are to keep climate warming below 2°C.

their relatively low materials requirements and the potential offered by the massive roll-to-roll production processes, despite their current small market share (5% in 2020). While monocrystalline silicon appears to have an unassailable industrial lead, the forthcoming market will certainly be vast enough to accommodate other technologies.

PREPARING THE CELLS OF THE FUTURE

Tandem cell development offers thin layers a chance, as they take the form of perovskite (PK) deposited in a thin layer on monocrystalline cells (see p. 41). "*Once we have achieved a 30% efficiency tandem silicon-perovskite cell, we will be able to produce a 25% efficiency silicon-perovskite cell,*" reckons Pere Roca i Cabarrocas. "*It will take research and investment to support a sector, but silicon has reached the end of the road. So, either we stop and pat ourselves on the back for the small improvements we have achieved (bifaciality, trackers, etc.) or we move on to the next stage.*" The greatest contribution in a tandem cell comes from the upper cell that absorbs most of the light spectrum, Jochen Rentsch reminds us. We could consequently envisage different tandem combinations, CIGS-PK, PERC-PK, HET-PK, etc. "*Personally, I have little faith in thin film technology,*" Jochen Rentsch says with reservation, "*silicon is over-dominant in the market and has amassed too much experience to give thin films a chance.*" A similar question could be asked about cells, III-V cells, capable of taking efficiency levels above 40%. In contrast with perovskites, we are already producing them in a very stable way, as they are manufactured for space applications. But their costs need to be 50 to 100 times lower if they are to be affordable for use in terrestrial photovoltaics. Anis Jouini doubts this can be achieved. "*The American NREL Best Research-Cell efficiencies chart is there to remind us that we make progress where we invest resources,*" Pere Roca i Cabarrocas counters. "*The question is knowing which technology to back. But if we want a technology that takes 10 years to develop, the relevant R&D needs funding now. Either that happens thanks to a cavalier industrialist like Elon Musk, or the governments or the European Commission will set the course. All the major infrastructure programmes have been developed in this way, from nuclear to high-speed trains.*" ■

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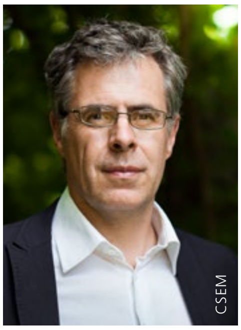
1. *At the end of 2020, the Fraunhofer ISE put global installed capacity at 708 GWp, while the IEA-PVPS put it at 760 GWp.*

EU PVSEC 2021 the European solar sector deals with its challenges



The 2021 EU PEV SEC conference provides a good opportunity for the various photovoltaic stakeholders to discuss the sector's major unresolved challenges, the technological progress made and new industrial developments. Christophe Ballif, Director of the Photovoltaics and Thin Film Electronics Laboratory of the Lausanne Federal Polytechnic University (EPFL) and the CSEM PV-center, and also Chairman of the Becquerel Committee from 2021 onwards, fills us in on the situation.

INTERVIEW CONDUCTED BY ARNAUD WYART

The challenge is to get photovoltaic to make deeper inroads into our towns, especially on façades.

What are the major challenges that this 2021 conference will address?

Christophe Ballif: The first is to design products that keep improving. This particularly applies to R&D on PV panels, which in a few years' time should pass the 23–24% efficiency mark. There is also the burning question of whether we are going to progress very much further with affordable multiple junction technologies. What is happening with research on perovskite cells is particularly interesting and absorbing. All aspects of reliability constitute a challenge in themselves… which leads me to say that this year's Becquerel Prize will be awarded to Ulrike Jahn in recognition of her specialist work in the field of module and system quality and reliability. In fact, as each new technology emerges, a tremendous amount of work goes on into reliability, but much of it is done behind the scenes.
Next, there is the building-integrated photovoltaics challenge, particularly in densely populated countries like Switzerland. How can we get photovoltaic to make deeper inroads into our towns, especially on façades? How can we ensure that a maximum number of solar panels is installed in built-up areas, even if output exceeds the consumption of the equipped buildings? There is no question of entering into competition with farmland areas. Now the last major hurdle to overcome is to set up strong enough leverage to implement energy transition, that really goes beyond statements of intent. Take for example solar… our annual installation rate in Europe should be 5 to 10 times higher.

Which are the major topics and highlights of this conference agenda?

C. B.: This will be a standout conference in that it will provide us with a full update on all the latest developments in crucial areas such as advanced silicon cells, perovskite cells, the reliability factor, panel performance (excellent results and new records have been made), storage, regulations, deployment, etc. Several sessions will also be set aside for special applications such as BIPV (building-integrated photovoltaics), agrivoltaics, floating photovoltaics, hydrogen mobility, and so on.

As for the conference highlights, European research centres have undertaken many projects on TOPCon-type passivated contact cells, which has led to the launch of a new class of devices. Work has also been carried out in the area of heterojunction cells, primarily in Switzerland by EPFL, CSEM (Swiss Center for Electronics and Microtechnology) and the Meyer Burger industrial group, which has just commissioned new production lines. Projects led by Oxford PV in particular on perovskite cells have made giant strides through a number of development stages. Turning to BIPV, significant headway has been made on developing techniques that now offer the possibility of tinting PV panels to turn them into building materials in their own right.

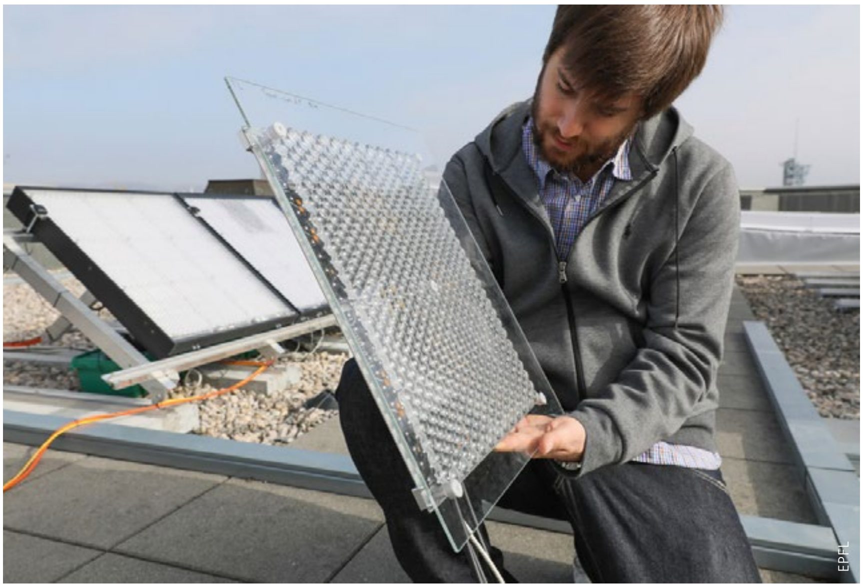
Will you be tackling issues relating to power grids?

C. B.: Yes, we will certainly be discussing all facets of grid integration and renewable energy management, in particular wind energy. We know, for example, that if Europe is to successfully achieve energy transition, it will have to install 150–200 GW of capacity every year. We are lagging far behind our goals, so one way or another, initiatives will have to be taken. “Smart” renewable energy integration, combined with short- and long-term storage, is bound to become absolutely vital and essential. However, if we look at the various scenarios (Eurosolar, Wind Europe, etc.), we don’t get anything like the same figures for wind and solar energy installation capacities, primarily because of the role given to hydrogen. Producing a lot of hydrogen will call for more renewable energies because of energy losses in the hydrogen chain. So, the scenarios will have to be tweaked and approved, but that will call for major research and modelling efforts. Besides which, the rollout of renewable energies and an energy mix with a high proportion of electricity, create a social and political challenge, as however certain the benefits are in the long term, the immediate cost is more obvious to

MEYER BURGER / CSEM

v *The Swiss equipment manufacturer Meyer Burger has become a heterojunction cell and module producer with the support of European research.*

The concentration modules made by Lausanne-based Insolight, are standardized for rooftop installation and offer 30% efficiency. >



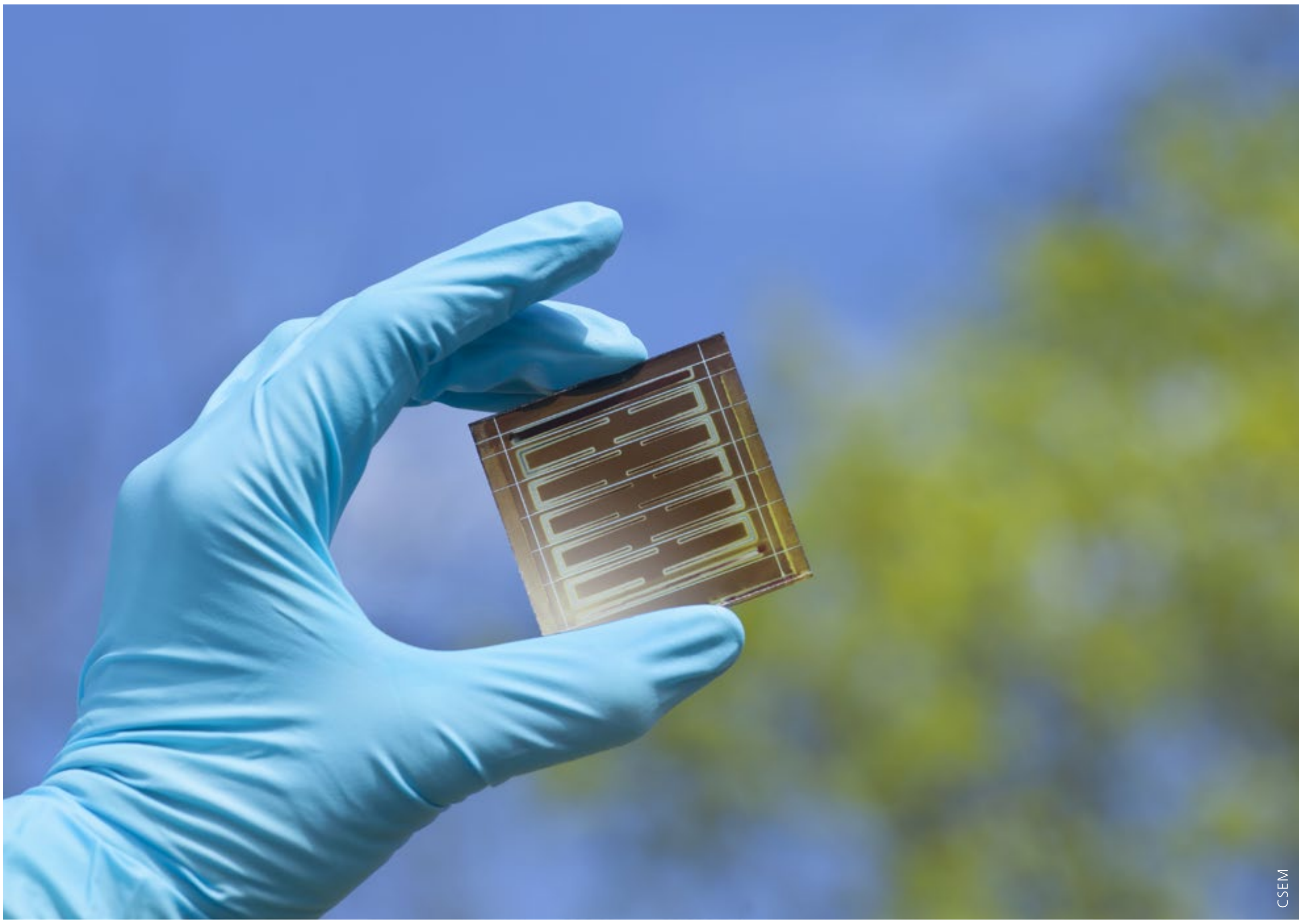
ordinary people. For this reason, there must be a drive to promote installations, but in view of the volumes at stake, it would be wiser if Europe did not become totally dependent on Asia. Consumers need to have a local alternative to keep part of the production, especially cell production, in Europe. That will also ensure a smaller CO_2 impact and that decent working conditions are guaranteed. A supply chain will have to be recreated and revitalized for that to happen… which is a very tall order!

Is European research boosted by recent industrial initiatives?

C. B.: Europe has excellent quality research sources and innovative companies at all levels. Nonetheless, keeping this ecosystem alive is contingent on production. Manufacturers' initiatives give the research community the justifications it needs to pursue its work and help convince governments to support it. A virtuous circle needs to be established. By the way, we fully realize that when certain technologies, such as thin layer silicon technology, arrived on the market, the existence of an industry meant that public funding was forthcoming. Once thin layer silicon could no longer compete with the fast progress being made by crystalline silicon, funding dried up.

Industrial initiatives that deserve to be mentioned are those of the Enel group in Italy, which set up cell production lines. In a strategy shift, Meyer Burger curtailed worldwide delivery of its solutions to concentrate on Europe and keep its expertise in-house. The group has commissioned a 400-MW cell production line. No doubt many equipment suppliers would like to sell in Europe if they could, but if they only supply customers in Asia, they run the risk of seeing their equipment and ideas copied and even improved. Consideration needs to be given to keeping innovations and production in Europe, while exporting manufactured products. The time-to-market notion, meaning the time required between the design of a product and its marketing, is important in this regard. In recent years support has tended to be restrained in Europe, especially during the transition phases from the pilot to the industrial phase. The European Union introduced a few tools, but they were too few and far between, and did not arrive in time. The European Green Deal, for example, gives scant attention to photovoltaic, yet if the industry is to expand as fast as possible, it needs considerable funding. Businesses for their part, appear to be reticent about working together, but they are keen to work with research centres. Initiatives of this type, if well run and backed by suitable financing instruments, could attract more support, primarily that of the highly effective European programmes. Joint academic research projects are developing, but it is hard to find good synergies and exchange data because of country fragmentation (different subsidy mechanisms, different constraints, etc.). We have the example

Manufacturers' initiatives give the research community the justifications it needs to pursue its work and help convince governments to support it.



^ *CSEM's single junction perovskite mini-module on 5x5 cm² substrate presented in 2015.*

of one perovksite cell initiative (EPKA) underway, but the road is long and there is room for improvement.

What are the disincentives to structuring new European sectors?

C. B.: Today we have a photovoltaic industry, comprising many modules manufacturers and a few cell manufacturers. We also have manufacturers of junction boxes, encapsulating sheets, inverters and installation systems. Furthermore, Europe has polysilicon and wafer producers. Yet, many of the players are too small to head off Asian competition. They need to differentiate themselves by coming up with more innovative and reliable products. Upscaling calls for real financial and political support, with the right mechanisms. As for the issues of the carbon impact and manufacturing conditions, a border tax should be levied on imports of products from high carbon emission countries. That would make European products more competitive. Users also need to be better informed. Are they ready to pay more to buy European panels and inverters? We are beginning to see some willingness to buy local, especially for small, roof-mounted installations. However, this is not happening on big installations, because every cent added to the kWh price will count, unless special constraints (e.g., in France with the CO_2 content) are specifically included in the project award criteria. It has also come to our attention that no import duty is currently levied on module imports, yet duty is levied on component imports (on glass, junction boxes, etc.). Thus, if we want to manufacture in Europe and source certain parts, we are penalized, which makes no sense. There is much to be done to promote the emergence and competitivity of European products at a regulatory level, yet we must remain pragmatic… the firm aim is to encourage the rollout of solar, not curb it. In an ideal world, demand for solar systems would be so high that it would make room for local products, running to the tens of GW, while we continue making some module imports and take advantage of what has been very efficiently implemented by many Asian manufacturers. ■

INES is located in Chambéry, France, halfway between Geneva and Grenoble.

JP GUERRINI / INES

INES has been serving solar innovation for 16 years

The French National Solar Energy Institute (INES) has been working on leading-edge solar technology developments and their industrialization, improving photovoltaic power grid integration and enhancing smart energy management ever since it was created in 2005. The Institute has created a broad network of industrial partners to move forward on these challenges.

BY GÉRALDINE HOUOT

"The Institute has become one of the world's leading lights in solar technologies with 13 participating laboratories"

Rewind to 1998. Back then, the former minister and European Union's chief Brexit negotiator Michel Barnier, was the President of the General Council of Savoie. He and his Vice-President Jean-Pierre Vial floated the idea of creating a collaborative research institute in the Savoie specializing in solar energy. They set sights on its becoming a global reference centre that would ignite local interest in the subject. The initiative was no mere pipe dream, as a clutch of manufacturing pioneers (Clipsol, the solar thermal collector manufacturer, Photowatt, the cell and module manufacturer, to name just two) operated in the region and there were also specialist local interest groups (including Hespul, and Asder – the Association Savoyarde pour le Développement des Énergies Renouvelables). The two council leaders galvanized the research sector (the French Alternative Energies and Atomic Energy Commission (CEA), Savoie Mont Blanc University, the CNRS and others) backed by the Rhône-Alpes region. It took 16 years for the French National Solar Energy Institute (INES) to be created in 2005.

The pair's gamble paid off, as the Institute has become one of the world's leading lights in solar technologies with 13 participating laboratories – 11 CEA laboratories – and two joint research centres – Savoie Mont Blanc University and the CNRS.

^ *Tests in real-world environments were completed for heterojunction modules in the Atacama Desert in Chile, in 2020.*

PUBLIC AND PRIVATE FUNDING

INES has an average annual global budget of 55 million euros. Since its founding, it has been funded to a total of 27% by regional players such as the Departmental Council of Savoie, the Auvergne-Rhône Alpes region and Savoie Mont Blanc University, to a total of 26% by funds dedicated to French and European research activities and projects and to 23% by the CEA matched like-for-like by industrial users.

It also has INES Formation & Évaluation (INES PFE), a 22 000-m² campus equipped with tertiary and technical buildings at Bourget-du-Lac that operates as a technical training platform for the region and businesses. It dispenses over 50 photovoltaic, thermal, building, energy and environmental courses, some in partnership with Hespul, in 350 m² of teaching and technical facilities with 1 400 m² of demonstration area. The Institute also organizes national and international conferences, and symposia. *"All in all, 500 people work for INES at Bourget-du-Lac with a further ten posted at Cadarache, near Marseilles, the site of the CEA's research centre whose facilities include large solar demonstration parks"*, Delphine Cherpin, Head of Communications for the Solar Technologies Department at INES CEA-Liten (Laboratory for New Energy Technologies) explains.

SIX RESEARCH AREAS

CEA-Liten manages the renewable energy technology-, renewable energy storage- and energy efficiency-centred R&D and innovation activities that revolve around six areas: high-efficiency photovoltaic, building- and vehicle-integrated photovoltaics, solar electricity storage and its grid integration, solutions for smart multi-energy grid deployment and operation, controlling the environmental impact of photovoltaic devices, and building energy management. The Savoie Mont Blanc University and CNRS joint research unit LOCIE (Optimization Laboratory of Design and Environmental engineering) focuses its work on building energy management. The centre, which occupies the middle ground between fundamental research and marketable products and services, has recruited 50% of its staff from research circles and 50% from industry. It works very closely with manufacturers, providing them with its expertise from proof of concept to industrial pilot. "*Company employees frequently come to work here at Bourget du Lac to see through a project to completion*", Delphine Cherpin adds.

STRONG TIES WITH INDUSTRY

The centre is particularly active in heterojunction technology (HET) and has been working in the field for fifteen years (see p. 38). Its pilot unit, "LabFab HET", has been up and running since 2012. It validates high-throughput bricks and processes (up to 2 400 cells per hour) in semi-industrial conditions and sets efficiency records that industry quickly adopts.

There are now strong ambitions for taking this technology forward, as several major groups have benefitted from the skills and tools available at INES. Examples are Enel Green Power, an INES partner since 2015, which, in conjunction with the CEA teams, achieved a 25% efficiency record on a 213-cm²

PV Module lamination and assembly at INES in 2021. >

INTERNATIONAL INFLUENCE

INES works in conjunction with many European and international bodies. It has taken part in 91 European projects since 2014 that have brought funds worth 19 million euros to the Institute over the period. On the international front, we should mention the Chilean ATAMOSTEC project (Atacama Module and System Technology Center), that aims to develop technologies for the solar photovoltaic energy industry in high radiation and desert conditions. *"It is a multi-party project created from a public-private technology consortium that brings together research centres such as the CEA INES, ISC and Fraunhofer Chile, manufacturers, universities of Chile… first and foremost the University of Antofagasta, political organizations and enterprises. It is co-funded by CORFO, the Chilean economic development agency"*, Delphine Cherpin points out. At the same time, a CEA-INES branch is being set up in Chile to accelerate the development of research and training in solar energy. Lastly, INES is a stakeholder in major cooperation programmes initiated by the French government. It is the technical representative for France at the International Solar Alliance, a group of 79 member countries intent on encouraging better use of solar energy.

active area. The company intends to increase its heterojunction panel manufacturing capacity from 200 MW to 3.3 GW by 2024 in its Sicilian plant, which will thus contribute to developing a cutting-edge photovoltaic industry in Europe.
Another example, is REC Solar which has been working with the CEA since 2020, exploring the feasibility of setting up a 4-GW heterojunction photovoltaic panel plant in 2025 at Hambach in the Great East region of France. Anis Jouini, Head of Solar Technologies Department at CEA-Liten and Director General of INES comments, "*CEA INES has proven its ability to transfer its laboratory results for silicon heterojunction cells and printed technologies such as organic photovoltaics to industrialization. It is now rising to the challenge of single-junction perovskite cells and tandem perovskite cells on silicon*".
Accordingly in 2020, CEA INES and the Institut Photovoltaïque d'Île-de-France (IPVF) launched their joint venture, "Tandem Made in France", to step up development of cells that combine perovskite materials with silicon heterojunction technology to create a high-efficiency (30%) device. "*Effective use will gradually encourage investors to prefer higher-efficiency, higher-performance panels, whose initial extra cost can be rapidly offset by the operating payoff. There is room in France, Europe and all over the globe along with new opportunities for industry*", Anis Jouini continues.
Start-ups have also been spun off from the work undertaken by CEA INES, such as Steadysun that develops solar energy production forecasting solutions. EDT ENGIE, the electricity utility service in French Polynesia can anticipate production variations more reliably at very short notice and so avoid power outages using this tool.

CONTRIBUTING TO ENERGY TRANSITION

In 2014 the centre responded to the French government call for applications to create Energy Transition Institutes[1] as part of the Investment in the Future Plan to strengthen its ties with industry, further promote technology transfer and massive development of photovoltaic power. It has been awarded aid by the French State for its successful bid. This ITE, called INES.2S, is a consortium of seven partners, operating under a public-private co-investment regime: Compagnie nationale du Rhône (CNR), the French renewable energy producer; COLAS, the road builder; RENAULT, the vehicle manufacturer; 2CA, the composite materials specialist SME, INES PFE training platform, the Savoie Mont Blanc University and CEA. Collaborative work with 2CA recently resulted in the company installing its first OPERASOL photovoltaic panel production line, which is geared to constrained applications such as the space and defence sector, joint work with COLAS has led to the marketing of Wattway Pack photovoltaic slabs and the development of Flowell dynamic luminous marking, etc. The first ITE project phase ended in 2018. A second phase has begun with goals defined through to 2024.

1. *The Energy Transition Institutes (ITE) are inter-disciplinary platforms specializing in decarbonated energies, that bring together the skills of industry and public research in an approach involving public-private co-investment and tight collaboration between all players.*

INES.2S, an Energy Transition Institute, is a new solar innovation player in France

Since 2019, the French State-endorsed ETI, INES.2S, has been rolling out research and development programmes and training courses. They are geared to paving the way for economic development opportunities for French industry in photovoltaics and seek to promote the wholescale integration of solar energy for energy transition.

BY ANIS JOUINI, EXECUTIVE VICE-PRESIDENT OF THE INES.2S INSTITUTE[1]

^ *Anis Jouini, Head of Solar Technologies Department at CEA-LITEN, Director General of INES and Executive Vice-President of INES.2S*

Energy Transition Institutes (ETIs) are interdisciplinary platforms operating in the field of decarbonized energies. They bring together industry and public research by applying a public-private co-investment approach and encourage cooperation between stakeholders to bolster the industrial sector's drive. France has seven such institutes centred on various subjects that are central to energy transition, and with their high emphasis on the collaborative approach, research is multipartite. They seek to make a positive impact by creating value for all partners by pooling knowledge and turning it to good use in industry.

INES.2S is based on the commitment of seven complementary partners who have formed a consortium. These major industrial players are the renewable energy producer CNR, Colas, Renault and the company 2CA, the INES PFE training platform, the Savoie Mont Blanc University and the CEA.

The purpose of the INES.2S institute is to pave the way for the new economic opportunities that solar development has to offer French industry and to promote the wholescale integration of solar energy for energy transition. Its roadmap and research programmes revolve around three main areas, that are complemented by knowledge sharing and training activities:

- solar technologies tailored to the constraints of their destination/usage,
- the most effective electrical and digital implementation in systems and networks,
- constant attention paid to their sustainability, reliability and economic viability to ensure their bankability.

INES.2S is recognized as an ETI and thus has the backing of French State aid that was awarded under the Investment in the Future Plan[1]. Its governance is organized around a strategic, private sector dominated steering committee and an international scientific board.

THE PATH TO PHOTOVOLTAIC INTEGRATION

INES.2S focuses on the French industry's strategic areas – the technological aspects of photovoltaics, building- and vehicle-integrated systems.

France's building stock, with its area estimated to be over 500 million m^2, offers a considerable resource. Buildings represent a naturally available solution and so their use avoids the contrived exploitation of new surfaces. Producing energy directly at the point of consumption? Nothing could be more logical. But photovoltaics must adapt to this sector's requirements by devising tech-

^ *INES building in Chambéry, France.*

The purpose of the INES.2S institute is to pave the way for the new economic opportunities that solar development has to offer French industry.

nologies that suit the architecture cost-effectively, offer the right level of performance and reliability, and meet regulatory requirements. Thus, new kinds of processes and equipment must be developed to make up for the dearth of suitable solutions and release the very high potential market that has been held back from taking off. That is precisely what the INES.2S institute intends to do. It is also developing standalone, smart components such as windows that can be installed in all kinds of buildings, as part of its overall optimized vision of energy efficiency and comfort.
At the same time, the fast-growing electric mobility sector, with 10 million vehicles forecast by 2030, is giving rise to another strategic resource. Vehicle-integrated photovoltaics adds directly to driving range, while relieving the power grid of part of the charging load. Research conducted by INES.2S aims to remove the uncertainties surrounding the amount of energy produced in actual conditions and propose suitable photovoltaic and electrical technologies (energy management and power conversion). Therefore, the INES.2S institute works on developing solarized demonstrator vehicles.
INES.2S is also working on inventing and creating specific solutions for other types of urban resources and infrastructures such as roads, pavements and cycle paths. The Wattway and Flowell roadway paving and light-emitting panels developed with the Colas group are excellent examples of this.
Naturally, all these projects now factor in the environmental impact of their constituent components and solutions by developing lifecycle analysis assessment tools and through research into new materials conducive to eco-design and recycling.

INSERTION INTO ENERGY SYSTEMS

Over and above photovoltaics, our research and development extends to solutions for storage, smart management, and the converters required for integrating solar generated electricity into the energy mix.
In view of the known prospects, the requirements are high. America's Department of Energy (DOE) forecasts global requirements for power grid storage capacity at over 150 GWh p.a. in 2030, of which Europe will claim 20%. The main applications are peaking demand and energy arbitration, followed by in PV-storage hybridization. There are many storage technologies in the running besides hydraulic pumped storage, such as: lithium batteries, flow batteries, hydrogen storage, not to mention lead batteries and compressed air storage. As it happens, the production of lithium batteries is concentrated in China, but Gigafactory projects are emerging in France and Europe.
Power grid storage developments will call for developing system sizing and control software solutions. An additional

^ *Photovoltaic road paving Wattway (Colas) developped at INES.*

research area will be micro-grids whose capacities will also rise sharply.
INES.2S primarily aims to characterize, benchmark, model and troubleshoot storage technologies. It plans to improve electrical system performance levels by optimizing their electrical architecture and develop novel power electronics solutions, and lastly develop control and sizing solutions to maximize value and optimize their impact for the grids.

CLOSING THE CIRCULAR ECONOMY LOOP

The upstream part of the sector is very promising in the general context as the market is growing fast across all geographical areas. It is clear that there is genuine competition between players as they take advantage of photovoltaic's steady cost reductions. This underlying trend will continue, meaning that the industry players will have to redouble their efforts to bring down CAPEX and OPEX costs, while improving plant output.
Awareness of the environmental impact of our lifestyles, and the rapid growth of installed photovoltaic capacities increasingly beg the question of how virtuous equipment production and how effective their recycling are. They fuel the drive for optimized use and even a second life for photovoltaic products. This economic sector is still in its infancy, yet it offers real development opportunities. The INES.2S member partners are determined to address all of these technological development issues upstream, developments in data processing, the greater constraints of grid integration, the availability of surfaces, etc. To do so, they seek to reduce installation costs by optimizing new plants (bifacial, trackers, and so on) or with specific siting constraints/opportunities (floating PV, large rooftop power plants, linear power plants, etc.). They are working on early fault detection and maintenance to extend plant operating life. Lastly, work is underway on giving panels a second lease of life and recycling panels by developing increasingly efficient, low-energy processes.

For further details : www.ines-solaire.org/news/linstitut-pour-la-transition-energetique-ines.2s-complete-sa-gouvernance

1. *The ETI INES.2S is co-financed by the French government under the «Programme d'Investissements d'Avenir» (ANR-10-IEED-0014-01).*

solar integration
research, innovation, education

technological
electrical and digital
economic and environmental

INES.2S
SOLAR SOLUTIONS

French Institute of Energy Transition

www.ines2s.org

The ITE INES.2S is co-financed by the French government under the Programme d'Investissements d'Avenir (ANR-10-IEED-0014-01).

"We aim to become one of Europe's solar powerhouses"

The Île-de-France Photovoltaic Institute (IPVF) opened its new premises in Palaiseau (Essonne) in December 2018. It restructured around six action programmes in 2020. Roch Drozdowski-Strehl (left), its Chief Executive Officer, and Pere Roca i Cabarrocas (right), its Scientific Director give a broad overview of the Institute's new strategy.

INTERVIEW BY VINCENT BOULANGER

"Our work involves preparing for 'the next shot', but also working on improving the off-the-shelf solutions "

Can you explain what the restructuring of IPVF entailed?

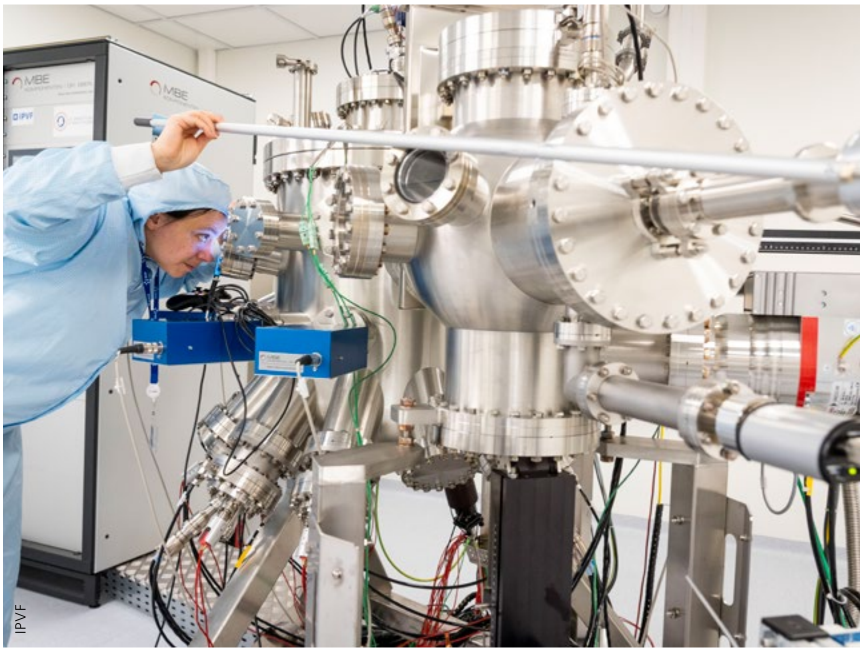
Roch Drozdowski-Strehl: IPVF is one of the energy transition institutes (ETI, see p. 24), tasked with organizing collaborative research, striving for scientific excellence and creating national solar research pools. We aim to mastermind technology transfer to industry to contribute to economic development and job creation.

Restructuring has centred around three main areas. The first structures our actions over three years around six programmes, geared to industry's needs. The second is international, primarily European in scope, rolling out transfers to industry on a European level. And thirdly, we have developed an ecosystem approach. We seek to link various players: research, innovation, solution builders and users. Our work involves preparing for "the next shot", such as tandem cells, but we are also working on improving the performance levels of off-the-shelf solutions… enhancing the yield of photovoltaic roof tiles, for instance, or research into colours for building-integrated photovoltaics.

Which are the priority focus areas of your work?

R. D-S.: Our three-year commitment is based on six programmes. Programme 1, "Economic and market appraisal", acts as our compass. The photovoltaic markets are very fast-moving. This programme aims to anticipate the developments in technologies, applications, costs, efficiency, etc. so that we can give exemplary guidelines to the R&D teams. The programme also focuses on analysing technology lifecycles, so that the circular economy takes centre stage of our work. Programmes 2 and 3, "Developing manufacturable perovskite-on-silicon tandem modules" and "Developing low-cost III-V tandem silicon cells", cover materials development, specifically focusing on lowering costs. Programme 4, "Characterization, modelling and reliability", covers materials analysis and sample characterization. Programme 5, "Solar to fuel", covers the production of hydrogen directly from solar photoelectrochemical cells. Lastly, Programme 6, "Proof of

Vacuum Manufacturing Cluster equipment: ultra-high vacuum coevaporation frame equipped with six sources (Cu, In, Ga, Se, Kf, NaF). It is commonly used for depositing CIGS layers on 10x10 cm substrates that can be heated up to 600°C. >


IPVF

THE IPVF IN A NUTSHELL

The Institut Photovoltaïque d'Île-de-France (IPVF) was founded on the initiative of the incumbent French government in 2013, as part of its drive to back the French PV sector. The IPVF started out as a public-private partnership, whose founding members included French energy operators EDF and TotalÉnergies, the French National Centre for Scientific Research (CNRS) and the elite École Polytechnique de Paris. Other partnerships with industrial concerns were swiftly set up, incorporating Air Liquide and equipment manufacturers RIBER and Horiba.

The IPVF has a technology platform in the heart of the Saclay campus, some thirty kilometres south-west of Paris, forming a meeting point for academic research and private players.

- 200 staff, including 150 researchers representing 25 nationalities
- A 8 000-m² platform, half of which is occupied by clean rooms for experimental work
- 15 theme-dedicated laboratories
- 100 leading-edge machines and items of equipment
- Some thirty patents to date, that will gradually be integrated into the IPVF Licensing Platform, inaugurated in July 2021 on the Institute's website.

www.ipvf.fr

concept for innovation breakthrough", works on technological breakthroughs to serve Programmes 2 and 3, and also prepares for the next shot, i.e., future generations of cells.

How can hydrogen be directly produced in photovoltaic cells?

Pere Roca i Cabarrocas: Water is electrolysed in an electrochemical cell, to separate water molecules into oxygen and hydrogen. The major national and international electrolyser projects in development are large, centralised facilities with high investment costs (Capex). Our idea runs quite counter to this. To avoid transport costs, we want to develop small, local-level units, as close as possible to needs. We are developing photovoltaic modules that incorporate electrochemical cells, that will reduce Capex, because the cell will be part of the electrolyser. The electricity will be directly used to produce hydrogen. To achieve this, we need to find inexpensive materials for the electrodes, that remain stable in the electrolyte. The final product will combine our best tandem cells with an electrochemical cell, offered in a decentralized unit.

What resources have you gathered to implement your programmes?

R. D-S.: In addition to our community of research workers, we have built up our operating and safety teams. Operational excellence is vital if we are to achieve our goal of being a state-of-the-art centre that is an international benchmark setter. Management of the technology platform (see inset on p. 30) is based on a team of cluster managers, created in 2020. All the cluster managers are experts in a set of procedures and equipment and will represent the researchers in talks with site operators, and vice-versa. They have the talent to smooth dialogue between the professions, set up recipes, best practices, and have thorough knowledge of the machines to draw the best out of them. So, the managers will guide the researchers in fulfilling their action plans, while capitalizing on their expertise.

Which projects are you working on with other French and international institutes?

R. D-S.: The ability to "hunt in packs" will be crucial to our success. We launched a strategic partnership with the National Solar Energy Institute (Ines) in 2020, for the purpose of designing a manufacturable tandem cell "made in France" (see p. 44). The partnership is based on the work being carried out by Ines on heterojunction cells and on our work on perovskite cells. We are also working with the German Fraunhofer Institute for Solar Energy Systems, ISE, on III-V cells, with the Belgium's Interuniversity Microelectronics Centre (Imec) on silicon, with Japan on third-generation

TECHNOLOGY CLUSTERS

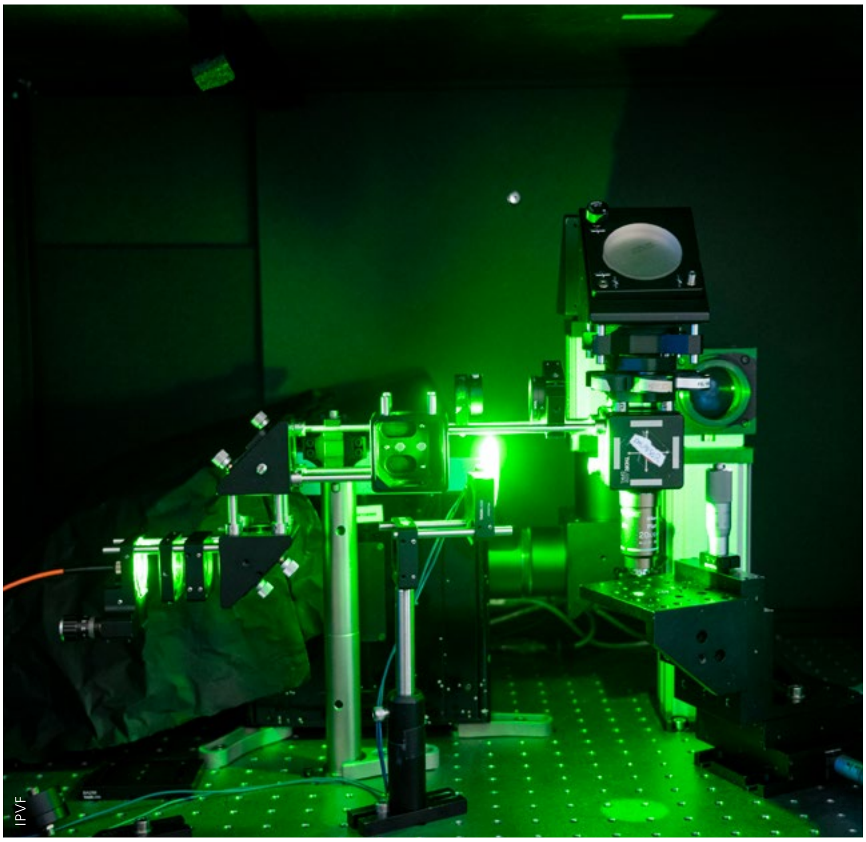
IPVF's technology platform is built around four clusters with 3 500 m² of clean room accommodation:

- **The Vacuum Manufacturing Cluster**, dedicated to new materials development. Evaporators, coevaporators, cathodic spraying, plasma deposition, ALD (Atomic Layer Deposition) and MBE (Molecular Beam Epitaxy) offer a wide array of techniques and materials (metals, semiconductors, dielectrics, barrier layers, antireflection layers, transparent conductive oxides, etc.) to design new functional layers that will be called on to integrate upcoming devices or serve as model materials for different processes.

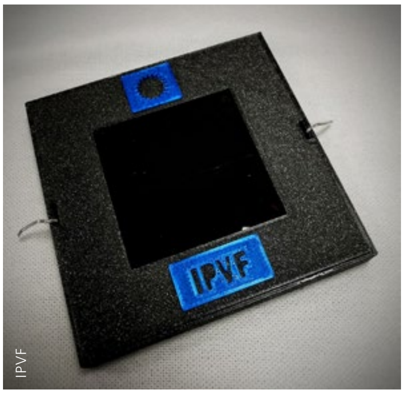
- **The Chemical Cluster** for wet chemical deposition and deposition of perovskite and conductive polymer layers. Researchers are also directly developing hybrid hydrogen production solutions through solar energy.

- **The Modelling & Characterization Cluster**. IPVF has all the in-house technologies needed to analyse the composition of materials, their opto-electronic characteristics and morphology at different scales (XPS, GDOES, SEM, and so on). The Institute is renowned for implementing one-of-a-kind luminescence techniques (4D, hyperspectral, spectral response and photovoltaic efficiency measurements), which enable full non-invasive studies of material to be conducted.

- **The Integration, Prototyping & Reliability Cluster**. IPVF develops complete device manufacturing capabilities. Thus, the integration of the photoelectric effect in sectors as wide ranging as the Internet of Objects, agrivoltaics, transport, building and energy-producing fabrics can be explored.


IPVF

^ *Optical bench for the characterization of solar cells.*



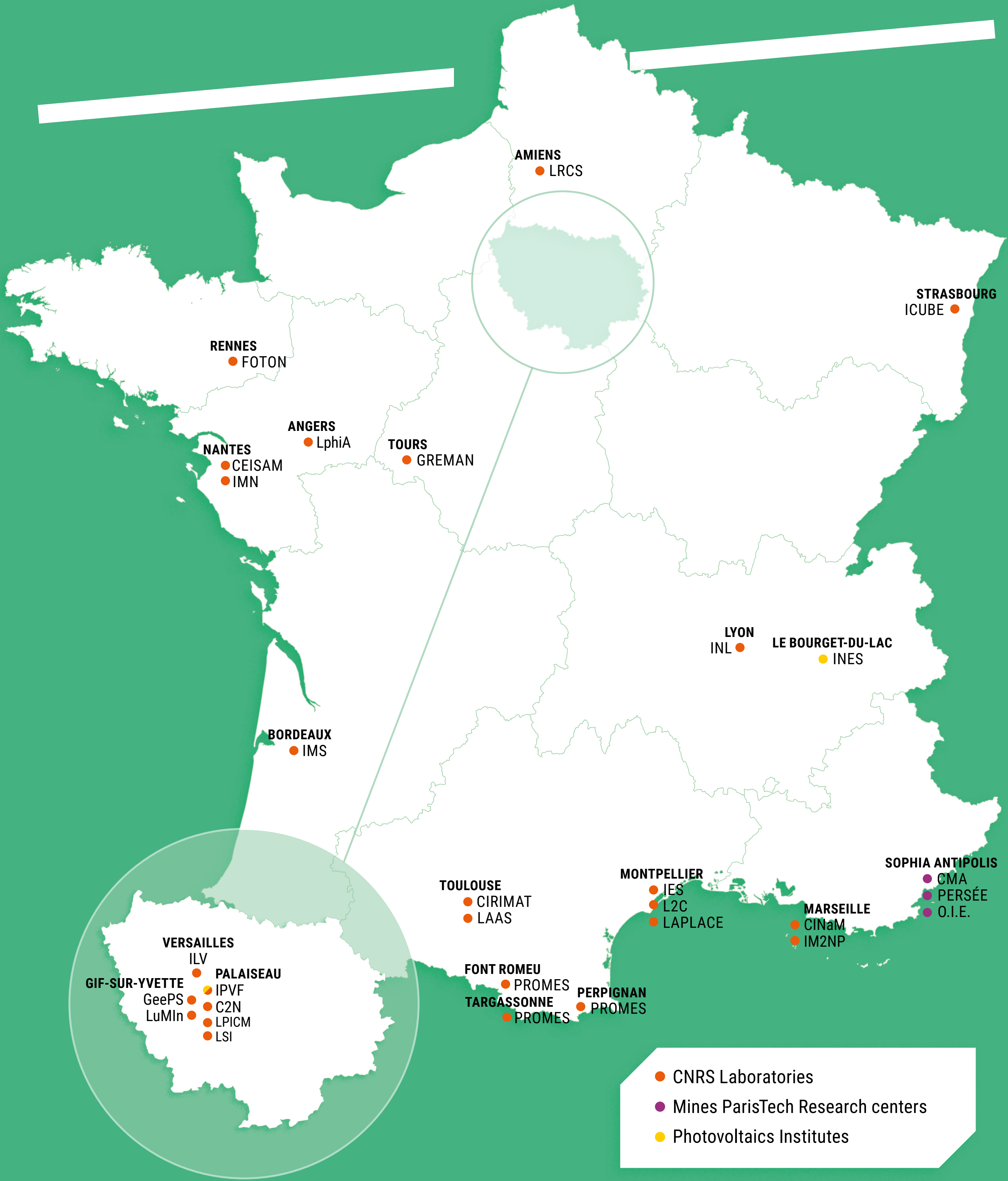
IPVF

< *Four terminal tandem device consisting of a crystalline silicon bottom cell and a perovskite top cell.*

cells and even with the American National Renewable Energy Laboratory (NREL) on costs analysis in connection with our Programme 1. We have also embarked on in-depth work to structure the sector, to build a first-rate solar "Team France". Recently we launched the IPVF Unite club, that draws on French solar photovoltaic value chain players. Thirty five members have signed up to date. Incidentally, we made considerable input into the launch and evaluation of the "Solar photovoltaic industry" call for expressions of interest. We are determined to strengthen the dialogue between research and industry, private- and public-sector, and also Franco-European dialogue. We aim to become one of "made in Europe's" solar powerhouses. The battle for solar has only just begun.

P.R.iC.: There was no vision of a European market for photovoltaic five to ten years ago. Now Europe is the world's second biggest market, worth tens of gigawatts per annum. The future lies with this technology. So, either we trust others with this future, or we take it on board ourselves and benefit from job creation. Our manufacturers are ready to take the plunge with the solar photovoltaic market as it displays such good prospects in Europe. Furthermore, initiatives are emerging in Germany, Spain and elsewhere. ■

Photovoltaic research in France



SOURCE: OBSERV'ER

C2N - Centre de Nanosciences
et de Nanotechnologies
CNRS JRU 9001
Palaiseau
www.c2n.universite-paris-saclay.fr

CEISAM - Chimie Et Interdisciplinarité, Synthèse, Analyse, Modélisation
CNRS JRU 6230
Nantes
ceisam.univ-nantes.fr

CINaM - Centre Interdisciplinaire
de Nanoscience de Marseille
CNRS JRU 7325
Marseille
www.cinam.univ-mrs.fr/cinam

CIRIMAT - Centre Inter-universitaire
de Recherche et d'Ingénierie
des Matériaux
CNRS JRU 5085
Toulouse
cirimat.cnrs.fr

CMA - Centre de Mathématiques
Appliquées
Mines ParisTech
Sophia Antipolis
www.cma.mines-paristech.fr

FOTON - Fonctions Optiques pour
les Technologies de l'information
CNRS JRU 6082
Rennes
foton.cnrs.fr/v2016

GeePS - Génie Électrique et Électronique
de Paris - CNRS JRU 8507
Gif-sur-Yvette
www.geeps.centralesupelec.fr

GREMAN - Matériaux, Microélectronique, Acoustique, Nanotechnologies - CNRS
JRU 7347
Tours
greman.univ-tours.fr

ICube - Le laboratoire des sciences
de l'ingénieur, de l'informatique
et de l'imagerie - CNRS JRU 7357
Strasbourg
icube.unistra.fr

IES - Institut d'Electronique
et des Systèmes - CNRS JRU 5214
Montpellier
www.ies.univ-montp2.fr

ILV - Institut Lavoisier de Versailles
CNRS JRU 8180
Versailles
www.ilv.uvsq.fr

IMN - Institut des Matériaux Jean Rouxel
de Nantes
CNRS JRU 6502
Nantes
www.cnrs-imn.fr/index.php

IM2NP - Institut Matériaux
Microélectronique Nanosciences
de Provence
CNRS JRU 7334
Marseille
www.im2np.fr/fr/accueil

INES - Institut national de l'énergie solaire
Le Bourget-du-Lac
www.ines-solaire.org

INL - Institut des Nanotechnologies de Lyon
CNRS JRU 5270
Lyon
inl.cnrs.fr

IMS - Laboratoire de l'Intégration
du Matériau au Système
CNRS JRU 5218
Bordeaux
www.ims-bordeaux.fr

IPVF - Institut photovoltaïque
d'Île-de-France and IPVF
CNRS JRU 9006
Palaiseau
www.ipvf.fr

L2C - Laboratoire Charles Coulomb -
CNRS JRU 5221
Montpellier
coulomb.umontpellier.fr

LAAS - Laboratoire d'analyse et
d'architecture des systèmes
CNRS UPR* 8001
Toulouse
www.laas.fr/public/fr/presentation-du-laboratoire

LAPLACE - Laboratoire Plasma
et Conversion d'énergie
CNRS JRU 5213
Montpellier
www.laplace.univ-tlse.fr

LphiA - Laboratoire de Photonique
d'Angers
Angers
lphia.fr

LPICM - Laboratoire de physique
des interfaces et couches minces
CNRS JRU 7647
Palaiseau
www.polytechnique.edu/fr/le-laboratoire-de-physique-des-interfaces-et-couches-minces-lpicm

LRCS - Laboratoire de Réactivité
et Chimie des Solides
CNRS JRU 7314
Amiens
www.lrcs.u-picardie.fr

LSI - Le Laboratoire des solides irradiés -
CNRS JRU 7642
Palaiseau
www.polytechnique.edu/fr/le-laboratoire-des-solides-irradies-lsi

LuMIn - Lumière, Matière et Interfaces
CNRS JRU 2036
Gif-sur-Yvette
www.lumin.universite-paris-saclay.fr

PERSÉE - Centre Procédés, Energies
Renouvelables et Systèmes Energétiques
Mines ParisTech
Sophia Antipolis
www.persee.minesparis.psl.eu

PROMES - PROcédés Matériaux
et Energie Solaire
CNRS UPR* 8521
Targassonne / Font-Romeu / Perpignan
www.promes.cnrs.fr

O.I.E. - Centre Observation, Impacts, Energie /Centre for Observation, Impacts, Energy
Mines ParisTech
Sophia Antipolis
www.oie.minesparis.psl.eu

Key

JRU *Joint Research Unit*

* *Own Research Unit*

FedPV – an academic research federation

For about a decade now, the French National Centre for Scientific Research (CNRS) laboratories have formed ties as the FedPV federation, which is a forum for dialogue and joint projects.

BY VINCENT BOULANGER

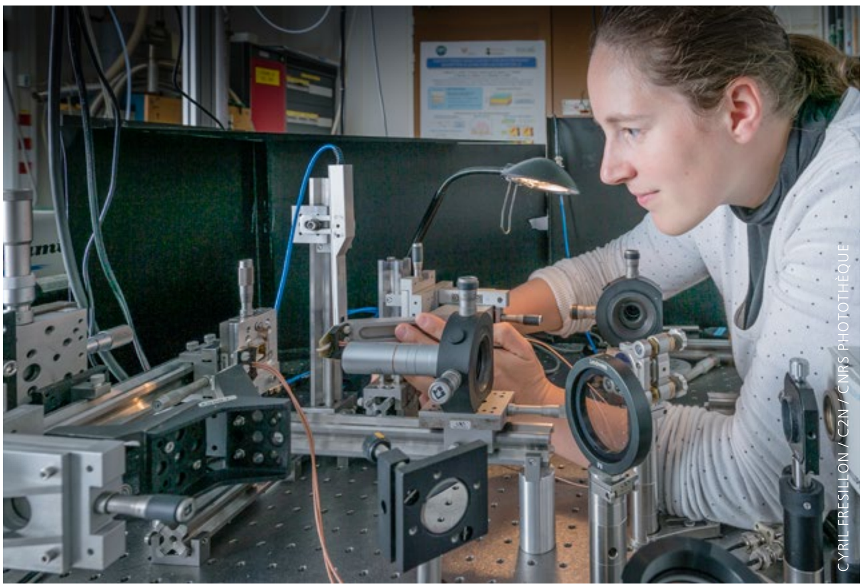
The French National Solar Energy Institute (INES) and the Institut photovoltaïque d'Île-de-France (IPVF) have become the showcases for current photovoltaic research in France. Yet, many researchers investigate a host of photovoltaic aspects in the various laboratories of the National Centre for Scientific Research (CNRS), which are scattered over the various universities, institutes and elite higher education establishments in mainland France (see map p. 31).
About ten years ago, five of the laboratories in the Greater Paris region – GeePs, ILV, IPVF, LPICM and C2N) decided to create the Fédération de recherche PhotoVoltaïque or FedPV. It now has 16 member laboratories, where some 220 researchers and doctoral students work. As Jean-Paul Kleider,

Positioning silicon samples for the deposition of thin alumina layers on their surface, prior to passivation, at the INL, Lyon.

CYRIL FRESILLON/INL / CNRS PHOTOTHÈQUE

^ *Focal spots of heliostats reflected in a cloud, above the THEMIS plant at Targassonne, near Perpignan. THEMIS is one of the first European concentrated solar power (CSP) and photovoltaic (CSP) technology R&D platforms.*

Selecting a gallium arsenide (GaAs) photovoltaic cell for measurement, performed at C2N, at Palaiseau. v



Director of FedPV and Head of the Materials division of GeePs explains, *"A CNRS federation has something of the status of an "extramural" laboratory, with its own remit and budget. We wanted to bring together the CNRS units that operated in a vacuum and create a common meeting ground in which to identify research priorities that encourage the laboratories to work together."* The Federation's board meets several times a year to define the photovoltaic research priorities and instigate strategies to promote dialogue between researchers. Every year for the last ten years, for instance, the FedPV has organized a four-day event, the Journées Nationales du Photovoltaïque (JNPV), which are attended by much of the French scientific community specializing in photovoltaics. Approximately 150 researchers converge on a tourist complex at Dourdan, about forty kilometres south of Paris. These days provide excellent opportunities for informal networking about research that can lead to new joint projects outside the formal analysis and result presentation sessions. "*Ties between researchers are much closer-knit since the federation was set up,*" *Jean-Paul Kleider believes. "They are considerably better informed about their colleagues' work and the openings for joint ventures.*"

COMPARING EXPERIENCES

Closer scientific partnerships are in step with photovoltaics' current trajectory. For as crystalline silicon cells begin to approach their theoretical efficiency limits, research is gearing up to combine different classes of materials and design multi-junction cells to take yields to new, higher levels. "*Formerly, every photovoltaic segment worked in isolation. Now the opposite applies,*" Jean-Paul Kleider asserts, "*We are trying to amalgamate the contributions of the various segments, and tandem cell developments will be the way forward.*" His laboratory offers a prime example as it is taking part in the European PERCISTAND (https://percistand.eu/en) project that kicked off in January 2020 and focuses on developing all thin-film perovskite-on-chalcogenide tandem photovoltaics.

While academic cooperation is vital to making new ground with solar technologies, these research projects must result in solutions that lend themselves to industrialization. "*The photovoltaic research community is not confined to academic research. More to the point, it must be guided by the need to promote solar and ensure that it becomes an energy transition driver,*" claims Jean-Paul Kleider. "*But it has to be said that working with industry is not always plain sailing, as our working cultures tend to be poles apart.*" FedPV held a day-long meeting with regional policymakers and industrialists in Nantes in 2019 to strengthen this dialogue. The meeting was intended to be held annually, but the coronavirus pandemic forced the cancellation of the 2020 and 2021 events. It should go ahead next year in Lyon. ■

Organic – solar's hidden side

Armor solar power film, is a French-German operation that has been manufacturing photovoltaic modules for about a decade. It has developed new partnerships to diversify its film's applications as it attempts to change perceptions of this emerging technology that complements traditional panels.

BY JEAN-FRANÇOIS GÉRARD

The German glassmaker BGT Bischoff Glastechnik integrated Asca films in the glass balustrades of a block of flats in Stuttgart Möhringen (Germany), inaugurated in May 2021.

Organic photovoltaic module technology is mature… at least according to the management of Armor solar power film. This French-German company is a subsidiary of the French group Armor at Nantes, that has been trading for nearly a century and that specialized in thermal transfer printing consumables for traceability on packaging, before branching out into organic photovoltaic (OPV) technologies in 2010. Its ASCA film uses technology based on polymers, oligomers or small molecules, coated with fine layers of liquid solutions deposited on thin film. The two plants, at La Chevrolière, near Nantes, and Kitzingen in Germany use a "roll-to-roll" coating process (see inset). The company also has two research and development sites, at Nuremberg and La Chevrolière. The result is completely flexible, semi-transparent and "*in theory any colour, depending on the chosen raw material,*" Sebastian Meier Vice President Corporate Development and Partner Management suggests. "*Size and shape are no longer issues thanks to the industrial process we have developed in recent years. The modules can range in size from a square centimetre to up to 4–5 square meters, depending on needs.*" All that remain to be found are the most suitable applications and the customers for this as yet unusual, and little-known technology.

^ *Organic cells lend themselves to all kinds of architectural design.*

The biggest challenge is to gain recognition for another photovoltaic technology, distancing ourselves from the crystalline silicon yardstick.

PRIORITY TO THE INDUSTRIAL PROCESS

For the time being, Armor solar power films does not aspire to take on the market for silicon photovoltaic panels. The latter offer better performance, but are heavier, rigid and opaque. Armor's flexible modules provide 4–5% efficiency outdoors and are striving to achieve 7% by improving the use of innovative materials.

An additional advantage of organic modules is that they can produce energy indoors by harnessing artificial light. In this case, the ASCA OPV module yields rise to 12–13%. Once again, the materials currently being tested are expected to reach a performance level of 20% for mass-produced parts manufactured by the group's plants. In the autumn of 2020, a record 26% was achieved in laboratory conditions by integrating new, latest-generation photoactive materials developed with Raynergy Tek, its Taiwanese partner, that specializes in organic semi-conductor materials for OPV. The variance can be attributed to OPV's absorption spectrum that overlaps well with the transmission spectrum of indoor light sources, such as LEDs. Thus, more of the incoming light is effectively converted into energy.

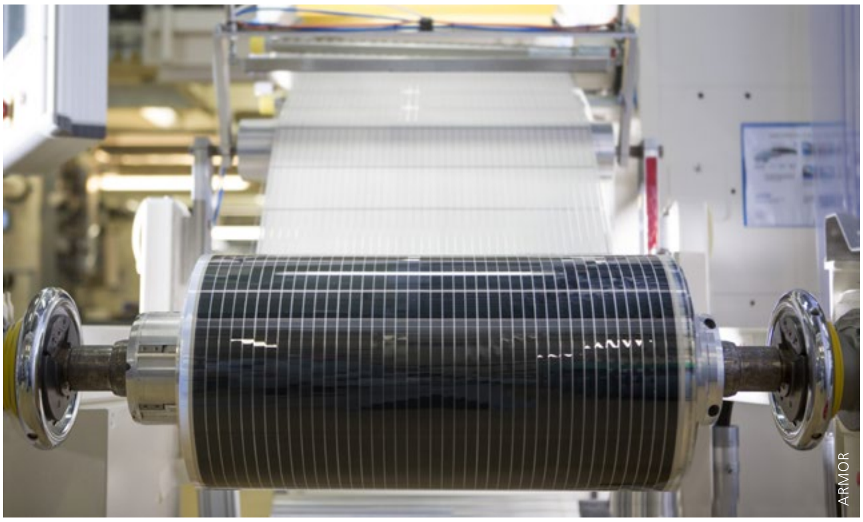
Yet, the company's key progress priorities are not so much to improve its modules' efficiency, but to "*reduce our own industrial manufacturing costs, increase the volumes, while introducing new quality control measures or new materials*", as well as "*finding cheaper raw materials that offer constant performance rates*", Sebastian Meier adds, besides, sticking to project agreed lead times against the backdrop of keen global competition for raw materials procurement.

BUSINESS PARTNERSHIPS

Leaving aside technical issues, OPV has struggled to raise general public and trade awareness of its merits. Armor solar power films has tried to remedy this by forming partnerships with some ten companies specializing in various sectors, such as glazing manufacture, facade elements and even membranes and other metal-textile structures in the construction field. One of these ventures has led to the installation of modules in horticultural greenhouses. Their aim is to promote OPV to their contacts, then find solutions to enable OPV to be integrated into projects to the best aesthetic and technical effect. "*Our biggest task is to change mindsets, because everyone thinks of solar panels as we are used to seeing them on roofs. Now it will be possible to fit OPV precisely where silicon panels are excluded*", Sebastian Meier continues. In one of the most recent projects, Armor solar power films has produced glazed balcony railings, some of them curved, for a four-storey apartment building in Stuttgart. All the guard rails are interconnected. The finish is transparent on the dwelling side and semi-opaque green as seen from street level to improve the residents' privacy.

The company is working on an even more ambitious record-breaking project comprising more than 10 000 modules, i.e., more than 1 300 m², which should materialize by the end of the year. The only detail the company has disclosed so far is that the customer is in Europe. Sebastian Meier interprets this project as a sign that the market's maturity is changing: "*It all depends on how acceptable these innovative solutions are to people. In Asia, they are more receptive to these new solutions, especially on small*

Armor has a manufacturing plant near Nantes with annual production capacity of one million m². >



FIVE YEARS OF MANUFACTURING

Commercial manufacturing kick-off date: 2016

The number of m^2 installed to date: "several tens of thousands"

The production capacity of the Nantes plant is 1 million m^2 and that of Kitzingen is 100 000 m^2, namely roughly 50 MWp and 5 MWp respectively

60 employees

articles. While in Europe, OPV technology is gradually gaining in acceptance in the context of climate change. The advantage of this technology is that it is attached to products but does not transform them."

USEFUL LIFE TO ORDER

Sales activity now centres on three areas: building integration, transport (buses, vehicles, bus stops, etc.) and the internet of things. The AtmoTrack real-time pollution sensor won an innovation competition ran by ASCA. "*Integrating a photovoltaic solution to our catalogue seemed obvious to us. The ASCA OPV film free of rare metals and toxins enables us to meet our environmental requirements and ticks all the boxes that are vital to us. Now, we can develop a technical product, that is 100% recoverable and Made in France*", Dorian Leblond, mechanical design engineer at AtmoTrack, points out. Armor solar power films hopes to take advantage of the boom in measuring instruments, sensors and real-time data transmission, whether it targets professional instrumentation or everyday personal items. ASCA films can replace the use of a battery or serve as an add-on, for instance to extend the range of a smartphone battery by a few hours, depending on the amount of energy required.

The modules offer 7–10 years of useful life out of doors without significant loss of capacity (less than 20%). The company reckons that its modules should have a useful life of up to 20 years, but these are estimates to be viewed cautiously as they are based on accelerated aging test results. The company has about 25 employees in Germany and 35 in France. It claims to be enjoying an increasing upswing in the number of projects but has not disclosed the manufacturing load factor of its plant near Nantes. Its maximum production capacity is designed to coat a million square metres per annum, which equates to 50 MWp in theory at current performance levels. Once again, the figure should be put into perspective as Armor solar power films is trying to initiate a benchmark change as capacity needs differ from one article to another.

Ten years down the line, the specific positioning of organic solar modules is still subject to differences of opinion between the company and the scientific institutes and universities, according to Sebastian Meier: "*Academic research, that publishes more than the companies of the small OPV community, focuses on in absolute efficiency and materials that are not used industrially. They do not always have access to the materials we use. Sometimes it is more useful to forfeit the last 10% of efficiency to increase stability and enable a product to be marketed. Useful life depends primarily on the needs of individual applications. We aim to offer maximum lifetime for films that will be integrated into a building's facades or its glazed surfaces. In contrast, when we are developing a solution to extend a smartphone's battery life, we view it as an item that will be in use for two to three years, so there is no need for it to have a ten-year useful life. With each individual project we need to find the right trade-off using materials that can be easily used industrially and are suitable for the size of the modules. The more efficient materials involve many synthesis phases that are complex and costly. We do this upstream value-for-money work with our suppliers.*" ■

Heterojunction – the winning combination

CEA-INES has raised its research work to a level that is likely to appeal to manufacturers, by acquiring a pilot heterojunction cell production line. This technology is establishing a footing in Europe as progress continues.

BY ANNE-SOPHIE PERRAUDIN

^ *The CEA-INES pilot line was among the first in Europe to harness heterojunction.*

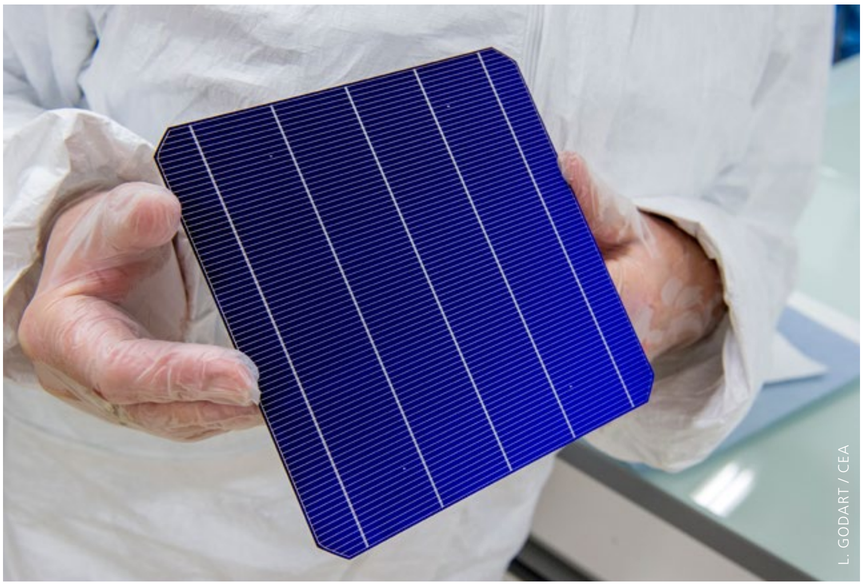
At the dawn of the millennium, photovoltaics began to catch the imagination of microelectronics researchers at CEA-Grenoble. They made their first foray into the subject by reviewing the existing technologies, which included heterojunction (at the time being developed by Sanyo of Japan) that particularly caught their attention. Indeed, this technology – which is based on bringing different materials into contact, monocrystalline silicon and amorphous silicon as it happens – entails applying similar techniques to those of microelectronics. Yet at the time, ongoing research at the centre was curbed by the fact that it had no specialist photovoltaic equipment.

The context changed in 2006 when Ines was created. Partnerships with equipment manufacturers were entered into deliberately to develop heterojunction. In 2010, the Institute was the first to achieve 20% conversion efficiency using this technology. However, because of the size of its equipment it could only handle small amounts. "*Our board realized that it was worth pursuing and committed to installing a pilot production line*", Charles Roux, who heads research activities on advanced cells at CEA-INES in Chambéry reports, "*The aim was to continue developing this technology with similar high throughput equipment to that used by the photovoltaic industry.*"

PROOF BY EXAMPLE

The CEA-INES pilot line, which was commissioned in 2012 near Chambéry, to emulate a factory line, was the first in Europe to harness heterojunction. Many challenges had to be overcome. It had to guarantee production speeds to equal the existing rates of other photovoltaic technologies and increase the model's economic viability while improving efficiency.

Heterojunction cell produced on the CEA-INES site. >



"We churned out tens of thousands of plates with an average of 20% efficiency to convince the manufacturers of heterojunction's usefulness. There was nothing to match it in the world."
– Charles Roux, CEA INES Chambéry.

At the time, the product sold by Sanyo was very expensive. So, CEA-INES sought to lower manufacturing costs primarily by simplifying the system and producing larger plates than the Japanese design.
"*We overstepped our role as an institute to convince the manufacturers of heterojunction's usefulness by churning out tens of thousands of plates with an average of 20% efficiency,*" said Charles Roux. "*There was nothing to equal it in the world.*"
Subsequently, CEA-INES pursued its platform and technology developments, primarily by reducing the material cost and plate thickness, by increasing substrate size and throughput and improving the efficiency level – achieving 25% in 2020.
The period also saw an increase in joint projects, primarily through technology transfers with European equipment manufacturers and an Italian manufacturer that opened a dedicated factory in 2019.

"RESULTS YOU CAN DEPEND ON TO REPEAT THEMSELVES"

Where CEA-INES' approach to heterojunction differed, was that it combined research with manufacturing. In the first instance, it carried out its traditional role by conducting studies geared to improving performance levels (by working on the materials and processes), and secondly, it went beyond its normal remit by transferring them to automated industrial equipment. "*Usually, an institute presents demonstrations on small quantities and only retains the best.*" Charles Roux explains. "*Thanks to our pilot line, we also produce them on a large scale and provide statistics to guarantee results you can depend on to repeat themselves.*"
Admittedly, proceeding with both of them in tandem was a tall order. By way of illustration, the high efficiency values achieved in the laboratory were 5 points higher than those coming off the production line until the researchers managed to close the gap. As Charles Roux observes, "*Working on actual size equipment calls for more effort and commitment, but that forces the pace of system maturity for its transfer to industry.*"

PROMISING SPECIFICS

When the model was considered complete, the research was extended to the module as a whole. All its aspects were examined and optimized, from cell encapsulation to their electrical connections. "*We were determined to go all the way with the module so that it would outperform moisture resistance and temperature variation standards to guarantee their service life,*" notes Charles Roux. Accelerated aging tests were conducted, that ensure stable performance for a minimum of 20 years.
Furthermore, as heterojunction is naturally bifacial, the research workers developed two types of module. The first, monofacial, is primarily intended for roof-mounted installations. The second, bifacial, is meant to be used in ground-based installations. Logically, its yield is higher than that of monofacial modules, but it also performs better

The former Solar World plant (facing) at Freiberg (Germany) is now home to Meyer Burger's heterojunction module assembly lines. Cell production is located at Bitterfeld-Wolfen, some 140 km away. >

INTERDEPENDENT PARTNERS

Broadly speaking, the prime focus of the work carried out by the Institute is to contribute to the development of the French and European industrial fabric, to enable large concerns to make a comeback and support their initiatives to do so. Thus, practical application is the aim of all commissioned research, and is interdependent of partners and funders.

In the case of heterojunction, it is the Institute's initiative, for it is the Institute that put this technology's development its roadmap and only then looked for partners likely to be interested by the approach. *"As we are not 100% State-financed, we have to find external partners and contributors, be they institutional or industrial"*, Charles Roux explains. *"That is how we sustain our roadmap and prepare future technologies, through all their development aspects."*

Thus, partnerships are created with each of the stakeholders along the chain to orient, fund, implement and transfer all or part of the processes. The same goes for suppliers of an input product for the composition of cells and modules and equipment manufacturers (like Meyer Burger at the time) and cells and modules manufacturers (such as Enel Green Power).

In other instances, external bodies call on the Institute for developments that are off their roadmaps – primarily on new uses, where heterojunction is concerned: road surface-integrated modules (with Colas), linear power plants along rivers and railway tracks, car parks, vehicles, boats, drones, stratospheric balloons, spacecraft and even consumer goods.

than its direct rivals. "*The bifaciality factor of heterojunction cells can exceed 90%, whereas currently available cells based on other technologies do not exceed 80%.*" Charles Roux comments. Not only that, but they perform better when temperatures rise, losing 0.25% of efficiency for every one degree Celsius increase in temperature compared to 0.35% by their counterparts.
These capabilities are supplemented by fineness, that the researchers have harnessed by developing a module that incorporates cells less than 100 microns thick. "*This technology is practically the only one that allows this thickness*", notes Charles Roux. It has to be said, that mass industry is not particularly interested in it as yet, but the researchers have no doubt that demand for it will soon grow.

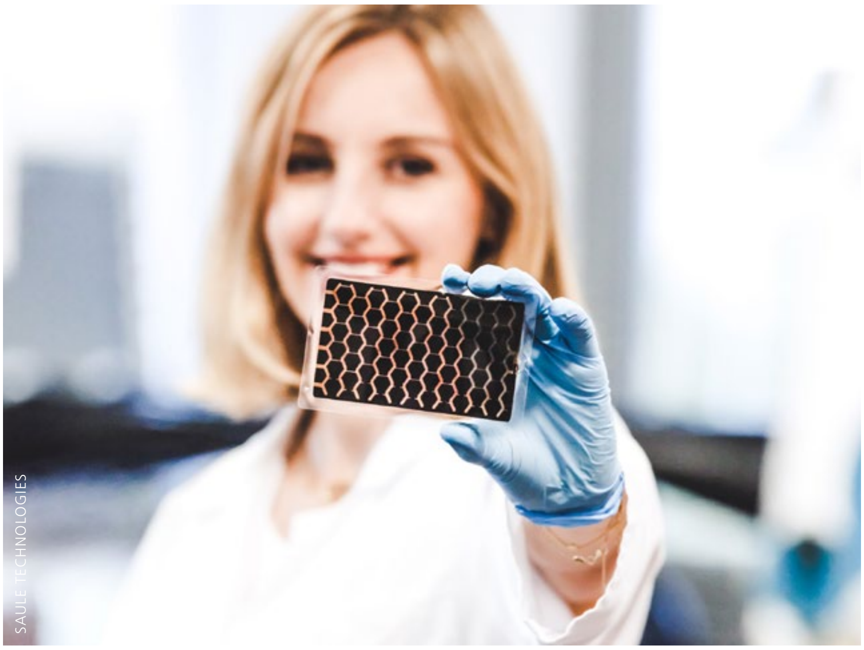
A "FAVOURABLE CONTEXT"

Many challenges need to be resolved before the technology's success is secured. This particularly applies to plate sizing, equipment redevelopment (to guarantee production quality at fast throughputs), reducing the environmental footprint (which also depends on reduced energy consumption and resort to less use of rare materials), and ever-increasing efficiency. The relevant aim, is to target 30% by combining heterojunction's assets with those of perovskite to create tandem cells (see p. 44) that will overcome silicon's limitations.
This said, the results achieved by European heterojunction research are more than encouraging. Calculations show that despite the cost differences between countries, these modules are competitive on scales of several gigawatts. Technology transfers to manufacturers are going well. Soon the REC heterojunction cell-module factory in France will joint the ranks of Enel Green Power in Italy and Meyer Burger in Germany. "*The context is favourable,*" Charles Roux notes, hinting at "other contacts". ■

The magical powers of perovskite

There is a flurry of research underway on perovskites, whose exceptional properties offer bright prospects. The formula for capturing new markets is also one of the ingredients of the highly promising tandem cell technology. Europe leads by a short head and must quicken its pace if it is to win the day.

BY ANNE-SOPHIE PERRAUDIN



Saule Technologies' co-founder and Chief Technology Officer Dr Olga Malinkiewicz holding a perovskite solar module. >

The challenge for perovskite cells is to radically extend their lifespan and produce them at high output levels.

There has been light on the horizon for European photovoltaics ever since perovskite burst into the solar world a little under 15 years ago. "*We have lost the battle for silicon, but with this new material, we're still in with a shot*", Grégory Marque, Programme Director of the Institut photovoltaïque d'Île-de-France (IPVF), says with excitement. Indeed, harnessing its extraordinary properties offers good prospects.

To start off with, perovskite is inorganic material composed of calcium, titanium and oxygen ($CaTiO_3$), but this term now designates a whole set of similar crystalline structure compounds with the general formula ABX_3, whose A and B are cations (positive ions) and whose X is an anion (negative ion). Where it comes into its own is the range of elements or compositions of elements that can be used to make up A, B and X. It is even possible to use organic elements for the A site. Its properties can be altered by replacing certain elements of its structure, that will allow it to absorb a greater part of the light spectrum than silicon for example. And the results have come in fast. "*In just over 10 years, we have been able to match silicon's performance level in the laboratory,*" Grégory Marque reports. "*That's impressive and is what is driving the keen interest.*"

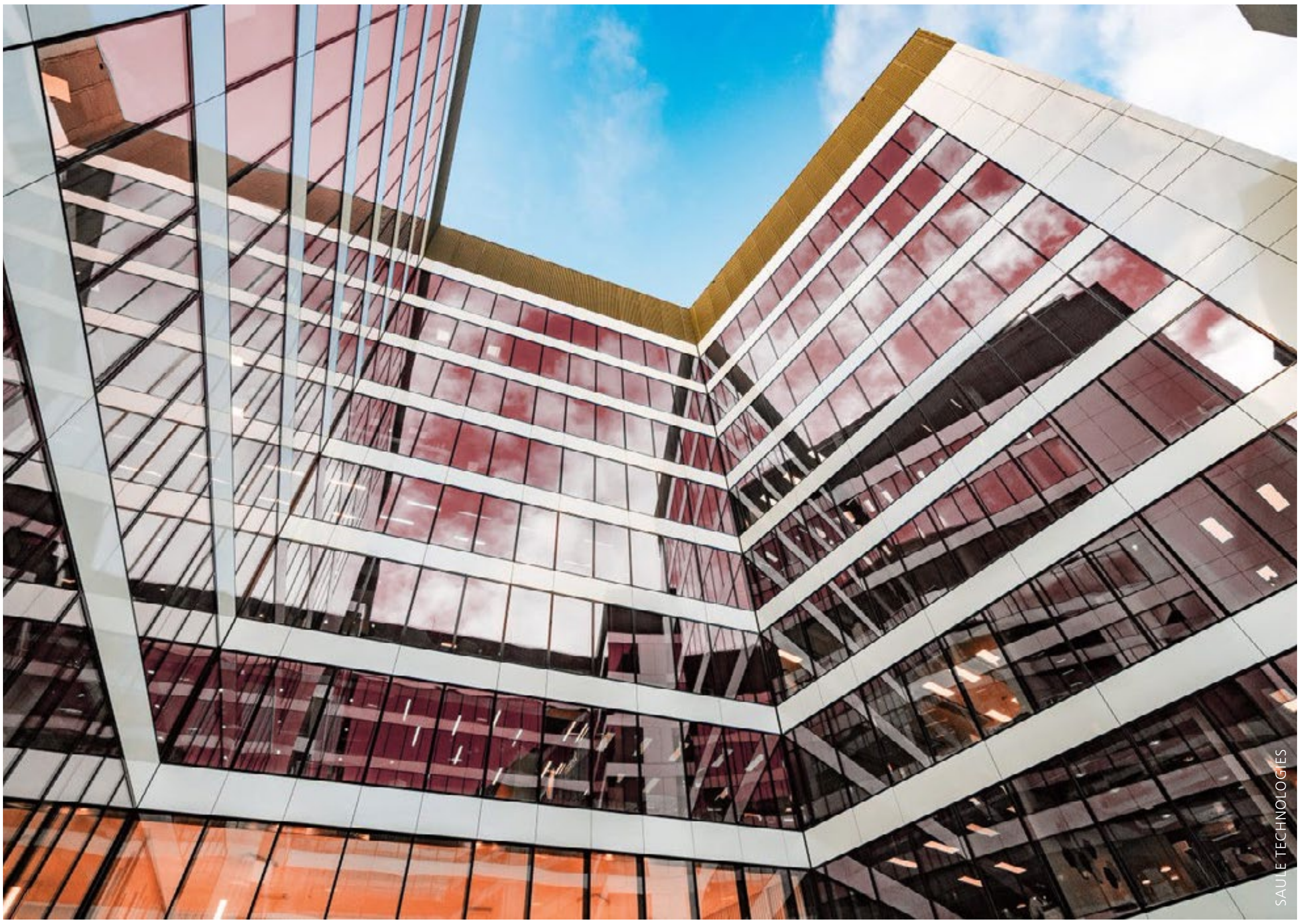
"THE POSSIBILITIES ARE ENDLESS"

If results of this order have been achieved so quickly, it is because manipulating perovskite is easy. In contrast with silicon, there is no need for heavy equipment. *"Almost any chemical laboratory can make perovskite,"* Grégory Marque notes, *"And as its elements can be varied and the ratios tweaked, there are endless possibilities to be explored."*
Synthesizing a material that converts light as efficiently as possible is not the only goal. "*The biggest challenge posed by perovskite is its stability.*" Grégory Marque explains. It degrades rapidly as it is sensitive to humidity and other factors. So, the researchers are working towards altering its composition and cell architecture to strengthen their resistance. While they have already managed to extend cell lifetime, the cells still degrade in a matter of hundreds of hours. "*With silicon, you can aim for over 25 years,*" Grégory Marque observes. "*It will be hard to sell perovskite if it cannot match this.*" In that case, its use could be restricted to small connected objects with limited lifespans.

PLANNING AHEAD FOR INDUSTRIALIZATION

For the time being, IPVF's researchers are essentially working on designing a stable, high-performance material. That is not tantamount to saying that they are indifferent to its industrialization, but it is bedevilled by two thorny issues. The first topic under study is the development of deposition processes that are compatible with industrial conditions. This relates to perovskite's sensitivity to humidity and the air as well as the need to achieve even layers of the material over large surfaces. In order to achieve industrialization realistically, a way must be found to obtain the same performance levels working in ambient air at high throughput. *"At our small scale, we have no difficulty spreading the material evenly, but how will we achieve this on large surfaces?"* Grégory Marque asks. One of the solutions envisaged is to use a coating technique known as "slot die" which is similar to the inkjet printing technique, that would offer the dual advantage of being suitable for use on flexible substrates. For another attribute offered by perovskite is that it can be

v *Perovskites could lead to having BIPV products with high efficiency levels.*



SAULE TECHNOLOGIES

SAULE TECHNOLOGIES

^ *Fraunhofer ISE reckons that VIPV's overall technical potential on trucks and heavy goods vehicles is 90.2 GW for the European Union alone.*

equally well deposited on a glass sheet or plastic film.

The second topic relates to the demonstrated toxicity of lead. While the quantities used are minimal, efforts are still made to substitute this element or improve its recovery during recycling.

"A MARKET RIPE FOR THE TAKING"

Perovskite research may well be far from complete, "*we are already starting to hear talk about its industrial manufacture*", Grégory Marque claims. In May 2021, Saule Technologies in Poland started up a flexible perovskite photovoltaic cell production line. Admittedly, the cell performance levels are still low, so they are more in competition with organic than with traditional panels. According to Dr. Dávid Forgács, Saule's Director of Knowledge Management, module efficiency depends on design and application requirements. It is typically 9–11% outdoors. In indoor lighting conditions (e.g.: 1 000 Lux, white LED) Saule's modules offer about 20% efficiency. Their precise lifespan has yet to be confirmed but seems long enough for the initial applications: "*We are currently working on our first commercial applications to test their real life performance. At the moment we estimate at least a few years' operation based on accelerated aging tests*", says Dávid Forgács. What remains clear is that the manufacturer is something of a trailblazer and a serious partner for European researchers [1].

Besides, marketing experts appear to be particularly keen on the idea of using perovskite technology for equipping connected objects, especially as the material offers the virtue of reacting well to artificial light (which, once again, does not hold true for silicon). According to Grégory Marque, it "*would be wise*" to start marketing the solution quickly on small items with short service lives, not only to get a foothold in the niche segment, but also because "*it would create the momentum for us to edge our way in.*"

Broadly speaking, some elements would lead one to believe that while European research is ahead of the field in this area, Chinese research is close on its heels. "*No doubt, there is a market ripe for the taking, but we must do it here and now, otherwise it will be too late.*" Grégory Marque notes.

Lastly, we all know that perovskite's future will not be as a solo player, but in tandem. "*We can work miracles if we pair it up with silicon, and achieve 42% efficiency,*" Grégory Marque explains. "*We devote much of our work to perovskite, but the actual goal is tandem cells.*" ■

1. *Saule Technologies is already part of the European Perovskite Initiative (EPKI): https://epki.eu*

The race for tandem cells

Tandem cell technology development is moving very fast. Thanks to the advances made, heterojunction silicon's limitations can be overcome by interfacing it with perovskite. The revolution is underway. The first to do this will spark it off.

BY ANNE-SOPHIE PERRAUDIN

^ *Tandem perovskite on silicon cell developed at INES.*

Heterojunction silicon cell technology is under development everywhere. For one thing, production is up and running, while research continues to optimize the model, aiming to offer the highest, most cost-effective performance levels. For all that, the conversion rate achieved using this technology peaks at about 25–26%. The record for the time being – held by the Japanese – is 26.7%, and the most optimistic prospects are for 29.7%. "*If we want to think in terms of reducing costs, we will have to improve on that figure*", says Solenn Berson, who heads Strategic Developments for Tandem Photovoltaic Cell at CEA-INES.

The problem lies in the fact that silicon sustains losses due to thermalization, among other phenomena, over a certain spectral range (of 300–750 nanometres, as it happens). The solution adopted to remedy this is to use tandem architecture, that involves coupling several different cell materials. The silicon, which responds very well over the 700–1 000 nanometre spectral range, is retained. Then, a

The two French photovoltaic institutes have allowed themselves 2 to 3 years to develop tandem technology on complete wafers using suitable industrial processes.

cell composed of a material that is more efficient over the 300–750 nanometre range is added. Now, perovskite not only meets this criterion perfectly, but it does not raise the cost of the overall device. "*Its outstanding properties make it the preferred material for developing this technology*", Solenn Berson points out.

Grégory Marque, Programme Director of the Institut photovoltaïque d'Île-de-France (IPVF), claims that efficiency upwards of 40% could be achieved by coupling heterojunction silicon and perovskites in tandem cells. "*If we get over this hurdle, that could be a game-changer for the future of European photovoltaics,*" he reckons. "*That really would be a revolution.*"

PRODUCTION IN OUR SIGHTS

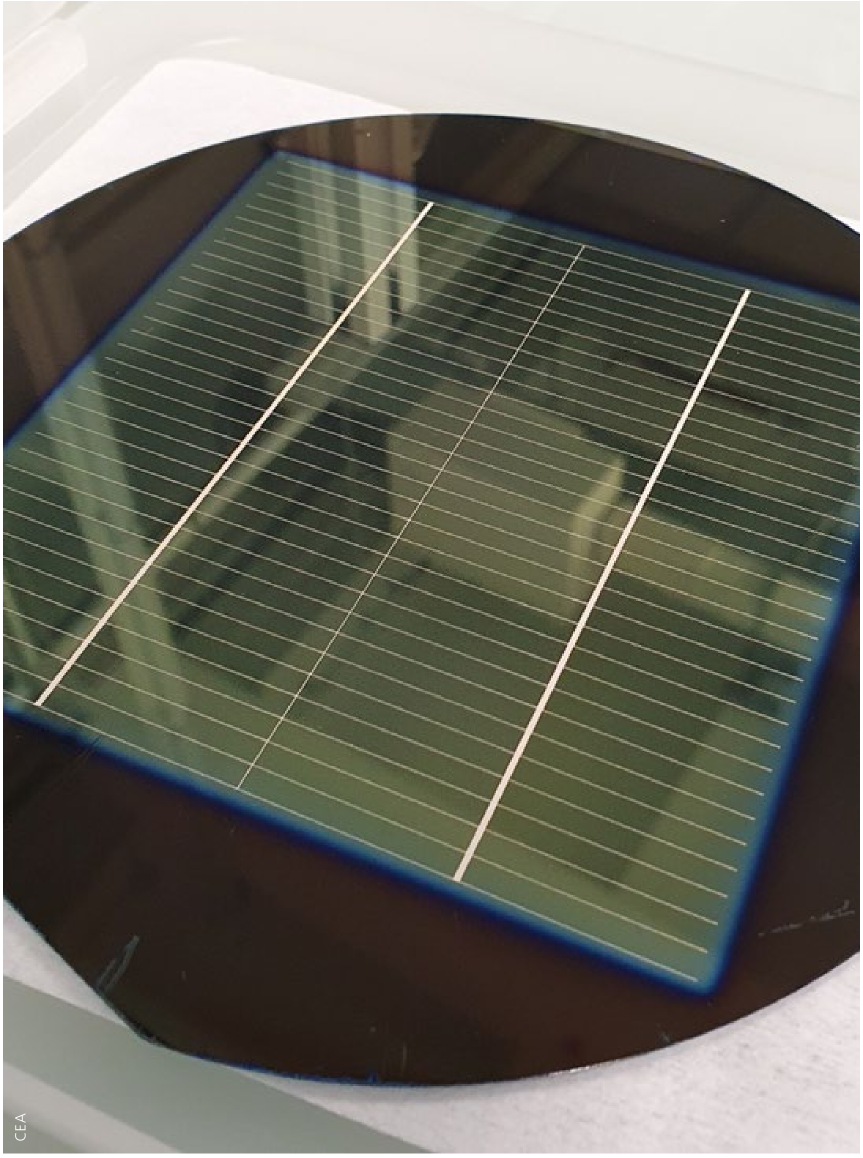
The concept is already proven and many institutions across the globe are researching the subject. So far, the conversion efficiency levels achieved revolve around 29.2%. Oxford PV set a record of 29.52% in December 2020 on a 1.12-cm^2 cell.

However, these results were achieved in laboratory tests on small surface areas. Now the challenge is to replicate these performance levels at a greater scale. "*There is huge potential, and everything is moving very fast*", Solenn Berson admits. "*We are already working on developing processes and equipment suitable for production.*" One example of this is that different material deposition techniques are at the exploratory stage.

CEA-INES has set itself a two to three year deadline in which to develop this technology on complete wafers with industrial processes and meet the goal of manufacturing modules that will guarantee the desired efficiency performance levels and reliability equivalent to those offered by current silicon panels. More research is required on perovskite junction. Results so far are good, but they need to be optimized and tested in real usage conditions. That said, Europe has been quick to take up research into this new material and can claim to be slightly ahead in this field.

CEA

100-cm² tandem cell produced at CEA-INES, Chambéry.



A JOINT PROGRAMME

In May 2020, the IPVF and CEA at INES, launched a joint photovoltaics programme. The aim of this "Tandem Made in France" initiative is to accelerate the development of cells that combine perovskite materials with heterojunction silicon technology to create a high-efficiency tandem device that can be transferred to industrial scale.

The two institutes, which have complementary skills, wish to accelerate the development of French cell technology that should achieve 30% efficiency, by promoting dialogue through joint theory papers and exchanging researchers working on this 3-year joint programme. The goal is to manufacture a tandem perovskite on silicon cell with two high-efficiency terminals using processes compatible with industrial production.

IPVF and CEA at INES have developed considerable perovskite synthesis and deposition process expertise and their integration into photovoltaic devices. In December 2019, CEA at INES managed to set an efficiency record of over 20% on the scale of an 11-cm² mini-module, while the IPVF has achieved efficiency performance levels of 15% on 25 cm².

Finally, CEA at INES is one of the heterojunction silicon cell manufacturing pioneers. This is one of the most interesting technologies for coupling with perovskites. Its teams succeeded in producing heterojunction cells offering efficiency upwards of 25% on industrial equipment capable of producing 2 400 cells per hour.

THE MANUFACTURERS ARE ALREADY AT WORK

What is clear is that given the sheer speed at which headway is being made, progress on the production side of things is essential. Equipment and pilot lines with short runs have started to spring up. The manufacturers are already at work, especially in Europe where Oxford PV is effectively blazing the trail. At the end of July, it announced that it had completed construction of its production site at Brandenburg an der Havel, Germany, equipped with its first 100-MW line. Despite the recent dispute with its former partner Meyer Burger, Oxford PV confirms that it still plans to launch production in 2022. Now Meyer Burger, which previously supported its equipment development efforts, has also decided to start manufacturing. Enel Green Power has also installed its first production line in Sicily on the strength of its joint work on heterojunction silicon technology with CEA-INES and announced its intention to open a bigger plant in Italy. "*The following step, will be to couple these cells to the development of tandem cells,*" says Solenn Berson.

It has to be said that the interest in this highly promising technology, is not confined to inside Europe's borders. There are other well-known initiatives in the United States and even more in Asia, which has well-established manufacturers. "*If a photovoltaic industry is to be built in Europe, it will be done by excelling in this type of silicon-perovskite technology, but we will have to work very fast if we want to be in with a sporting chance,*" Grégory Marque warns. ■

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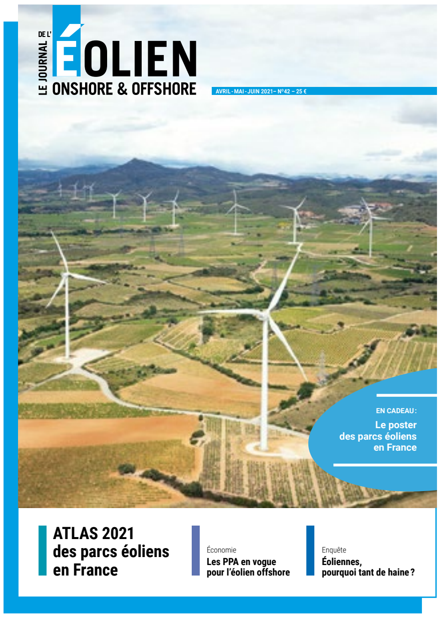

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