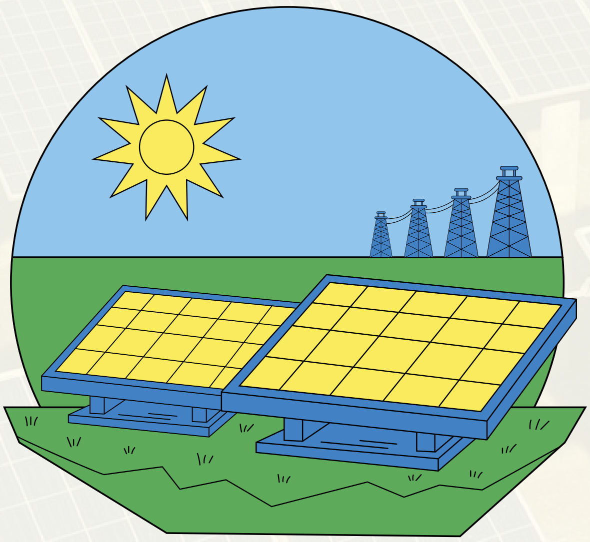
European Energy Research Alliance
Photovoltaic Solar Energy

2025

# Annual Overview



EERA Joint Programme on Photovoltaic Solar Energy

The 2025 Overview of the EERA Joint Programme on Photovoltaic Solar Energy is a new initiative designed to gather and showcase the diverse achievements of our network throughout 2025. This first-of-its-kind overview aims to provide a cohesive snapshot of the research, innovations, collaborations and project milestones delivered by our member organisations across Europe. The initiative has been structured as a simple but meaningful way to highlight the breadth and impact of our community's work, strengthening cohesion and mutual visibility within the JP PV network.

EERA JP Photovoltaic Solar Energy (EERA-PV) is one of the 18 Joint Programmes of the European Energy Research Alliance, with the objective of accelerating the development of photovoltaic solar energy to become a large-scale, cost-competitive and reliable energy technology. Through joint programming, aligned research activities, and shared expertise, EERA-PV contributes to advancing performance, cost reduction, manufacturing processes and system reliability to support Europe's climate goals.

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Member contributions included summaries of key results, project highlights, collaborations, knowledge-exchange efforts and outreach activities. These inputs are helping us build a representative and dynamic overview that not only reflects individual organisational achievements, but also illustrates the collective progress of EERA JP PV in 2025. Once again, we would like to express our gratitude to the members of our network who participated in this new initiative.

EERA
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## EERA Joint Programme on Photovoltaic Solar Energy in 2025

In 2025, the EERA Joint Programme on Photovoltaic Solar Energy (EERA JP PV) made substantial strides that demonstrate both the growth of the network and its increasing impact on the European PV research landscape. A key highlight has been the successful organisation and sponsorship of major community events that brought researchers, industry, and policymakers together to accelerate innovation. For instance, the **5th tandemPV Workshop in Hasselt (Belgium)** attracted over 240 participants from 27 countries, fostering interdisciplinary collaboration and showcasing cutting-edge developments in tandem solar cell research. EERA JP PV's involvement as an official sponsor strengthened dialogue across material science, device engineering, and system integration, underlining the programme's role in driving scientific exchange and cooperation.

Another major milestone was the **BecomePV 2025 workshop in Brussels (Belgium)**, which successfully convened experts and stakeholders for two days of forward-looking discussions on emerging PV technologies, including perovskite chemistry, tandem scaling, organic PV, and policy levers across the value chain. With active engagement from over 60 participants, this event reinforced the sense of community and facilitated meaningful networking opportunities that are essential for future collaborations.

In addition, EERA JP PV's participation in the **42nd EU PVSEC in Bilbao (Spain)** provided an important platform to represent the network at one of the world's leading photovoltaic science and industry conferences, further elevating visibility and enabling the exchange of insights with the broader international PV community.

In addition to the workshops and conferences mentioned, EERA JP PV proudly **sponsored ISOS 16**, the 16th edition of the International Summit on Organic and Hybrid Perovskite Solar Cell Stability, with the programme elaborated by EnergyVille (Belgium). We also **sponsored the International Winter School** "Innovation in Photovoltaics: from emerging technologies to system-level aspects" held in Bressanone (Italy), which provided an intensive learning and networking platform for early-career researchers.

Through these and other initiatives, the EERA JP PV network is delighted to help our members achieve the greatest possible impact from their events, providing support wherever we can to maximize visibility, collaboration, and knowledge exchange within the European PV community. While these activities highlight key achievements, they are only a small sample of the work happening behind the scenes.

We are deeply grateful to our network of members for their engagement, from participating in events to developing proposals and contributing to projects. At the EERA Joint Programme on Photovoltaic Solar Energy we work tirelessly to support our members and ensure their voices are heard across Europe, helping to amplify their impact and foster collaboration that strengthens the European photovoltaic community.

We are excited to continue supporting our members in 2026, with plans for new workshops, networking events, and collaborative projects. We hope to further showcase the outstanding work of our network and help every member achieve the greatest possible impact this year.

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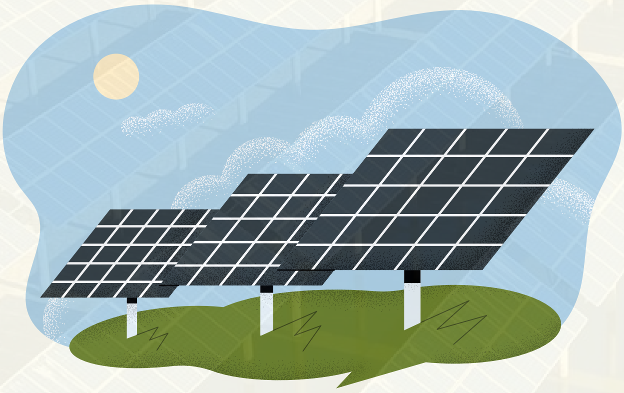

# Member activities 2025

European Energy Research Alliance
Photovoltaic Solar Energy

# List of contributing members

EERA
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Austrian Institute of Technology
Marcus Rennhofer

AIT is active in the field of PV in R&D projects and services in the international high-quality context.  Exemplary some research results are shown. These exemplary research highlights reflect AITs positioning as leading research center for renewable energy solutions for the future.

Within the AIT PV laboratory emphasis was laid on investigating alternative stabiliszation and power rating approaches in international context. Alternative protocols for emerging technologies were also tested within round-robin settings, as well as on field-aged modules of different types

AIT developed new models to evaluate the transferability and interoperability of AI-based PV models across different sites and plant configurations, as well as to compare the aggregation of plant-level data with federated modeling approaches.  Within research projects, insights were gained through analyses of the forecasting benefits of diverse methods, addressing model modularity, performance under sparse data conditions, interoperability, and forecast improvement. Methodologically, AIT aims to compare the performance of different analytical and AI models and to validate them using high-quality measurement data.

Austrian Institute of Technology
Marcus Rennhofer

Successful method development was successfully shown by combining site-specific, high-precision PV yield models with highly resolved climate models to evaluate PV yield development in Austria over the coming decades. The team has demonstrated the value of close cooperation between climate modeling and PV yield modeling, laying important groundwork for future projects in this interdisciplinary field.

A leap forward was made in the integration of PV modelling and techno-economic simulation framework TESCA, enabling a comprehensive evaluation of  techno-economic impact scenarios for renewable hybrid power plants incorporating  technologies such asPV, electric storage or hydrogen electrolysis.

Within expert committees regarding PV besides EERA, AIT is active in IEA PVPS Task 13, IEA PVPS task 13, IEA TC 82 and AIT hold the research chair in the international Photovoltaic Collaborative to Advance Multi-climate Performance and Energy Research (PV CAMPER).

CENER – Centro Nacional de Energías Renovables
Eugenia Zugasti

In 2025, CENER advanced the development of products, technology, and services across six strategic pillars: operation and maintenance, PV integration for specific applications, circularity of PV technology, PV applications, performance simulation in complex systems, and high-value testing.

Significant progress was made in optimising PV plant performance through two flagship initiatives. The Cloud Impact Nowcasting Platform secured funding to develop a cutting-edge system that predicts the real-time impact of cloud cover on PV plant output, combining sensing, data processing, and nowcasting to provide actionable insights for maximising efficiency. In the SOLID-PV Project, CENER helped establish advanced metrology tools to quantify and reduce uncertainties in PV system performance, aiming for harmonised, traceable, and continuously improving industry standards. Sustainability efforts included completing a recyclability index for photovoltaic products and advancing standardisation methods for eco-design and energy labelling, supporting EU initiatives such as the Ecodesign Directive and the Energy Labelling Regulation.

CENER – Centro Nacional de Energías Renovables
Eugenia Zugasti

CENER also strengthened its expertise in Building-Integrated Photovoltaics (BIPV) with the CECOM4PV project, successfully integrating PV technology into curved ceramic roof tiles to combine aesthetics with functionality for sustainable architecture. In agriculture, the IGUZKITZA agrovoltaic project co-located PV systems with olive tree cultivation, where CENER's SIMPV software enabled dual-modelling to optimise both land use and combined agricultural and energy yields.

To ensure the durability and reliability of next-generation PV technologies, CENER expanded high-value testing capabilities, including benchmarking novel technologies, adapting testing protocols to uncover new degradation mechanisms, and providing actionable insights to accelerate innovation and enhance long-term system resilience.

Through these initiatives, CENER continues to advance both technological innovation and sustainability in photovoltaic applications, addressing efficiency, circularity, and multifunctional integration across urban, agricultural, and industrial contexts.

Catalonia Institut of energy research (IREC)
Alejandro Perez-Rodriguez

During this period, the Solar Energy Materials and Systems (SEMS) Department has advanced its mission to conduct research on transversal topics within the photovoltaic (PV) technology framework, covering novel materials and PV applications, advanced system and characteriszation methods, and the evaluation of operation under real conditions. The three main pillars are:

**1.** Integrating photovoltaics across society by targeting ubiquitous, application-driven PV technologies. Key development areas span wide-bandgap materials for indoor PV, transparent PV, and device concepts and processes tailored for flexible applications. This agenda is being accelerated through a portfolio of emerging and re-engineered PV absorbers (a-Si, CZTS, $Sb_2S_3$, and ZnOS). The researchers demonstrated that nanometric amorphous silicon layers enable devices designed for transparent and indoor PV. In parallel, they advanced $Sb_2S_3$ performance for agrophotovoltaic concepts, achieving steady efficiency gains. Finally, they strengthened the scalability pathway for CZTS by establishing an operational pilot line, which also provides a unique testbed for machine-learning and AI methods, laying out the groundwork for data-driven, holistic device characterisation.

Catalonia Institut of energy research (IREC)
Alejandro Perez-Rodriguez

**2.** Development of self-driving laboratories, including synthesis and characteriszation of materials and devices, aiming to transform materials and device research through fast material inspection and accelerated materials discovery and analysis. Core efforts focus on the development of sensors, enabling rapid and holistic characteriszation, automation of synthesis and processing systems, and the implementation of explainable artificial intelligence methods for fast experimental analysis and design of experiments. These approaches enable full-process automation compatible with PV technology research, process optimiszation, and inline industrial process monitoring.

**3.** Dedicated research infrastructure for PV element testing under controlled and real operating conditions, integrating novel real-time monitoring methods and dedicated sensor platforms for both indoor and outdoor environments in operative conditions and stressed /accelerated conditions. These infrastructures enable technology validation and the development of cyber-physical digital twins for modeling and extrapolation of real-operation performance.

These activities have been presented at internationally renowned conferences such as MRS, E-MRS, EUPVSEC, ICMAT, IPVC-2, and CICC-14, and published in high-impact journals including Advanced Energy Materials, Energy Materials, and Renewable Energy, in active collaboration with leading research institutions and companies worldwide.

Centre for Renewable Energy Sources and Saving (CRES)
Evangelos Rikos

During 2025 CRES contributed to the research and dissemination of new PV applications such as Vehicle Integrated PVs and agriPVs. In the area of VIPVs, CRES completed the collaboration with the German industry Sono Motors GmbH (as part of the EU project ERIGrid 2.0) during which CRES offered testing services in commercial products (on-board chargers) for solar buses. As one of the achievements during this activity CRES developed a prototype PV emulator that allows testing of the chargers in a laboratory environment.

The novelty of the approach was the use of low-cost material, including IoT-based microcontrollers (Raspberry Pi Pico W), that allow for easy emulation of multiple PV panels at low voltage. The findings of this activity were presented in the official reports of the ERIGrid 2.0 project as well as at the ICRES 2025 conference that was held in Thessaloniki, Greece in April 2025. Regarding agriPVs CRES contributed to the methodological design approaches by collaborating with industrial and research partners in the frame of the EU project SolarHub. The activities resulted in developing tools for the PAR calculation as well as economic assessment of agriPV projects. The tools were developed using an open-source approach either using Python or MATLAB and are used by the designer of such a project to assess the amount of shading cast on the crop under the PV panels. In addition to that, a holistic methodology was also developed and elaborated.

Centre for Renewable Energy Sources and Saving (CRES)
Evangelos Rikos

This includes all necessary phases a designer must consider in order to develop an efficient agriPV project. The phases include the regulatory and market, the crop requirements and microclimate impact analysis, the definition of KPIs, the shading/PAR calculation that satisfies the crop criteria, the technical design of the project, and the financial assessment.

In addition, CRES contributed to the promotion of agriPV technology by organizing a dedicated workshop in Greece to present the technology and showcase a real-life project. Last but not least, the organization was recently equipped with a new 21 kW grid-simulator/power amplifie, which is used for testing PV inverters.

Centro Investigaciones Energéticas, Medioambientales Y Tecnológicas (CIEMAT)
Jesús Polo

In 2025, the CIEMAT's unit of PV materials and devices successfully secured funding for a high-profile collaborative project involving major Spanish research groups. This new initiative aligns with an ongoing project, with both dedicated to advancing the development of next-generation Photovoltaic (PV) technology. The projects collectively target several key areas in PV innovation in high-efficiency cell concepts (solar cells based on TOPCon structure), exploring the sustainability of industrial processes and materials, focusing heavily on environmentally friendly fabrication methods and waste valorization strategies.

In parallel with these new activities, CIEMAT's unit of PV materials and devices benefits from a strong background in characterisation, metrology, and performance analysis of PV devices under real operating conditions. The centre's facilities and expertise enable advanced electrical, optical, and reliability testing of solar cells and modules, supporting the transfer of high-efficiency concepts from laboratory to industrially relevant environments. Furthermore, CIEMAT's long-standing experience in resource assessment, outdoor testing, and system-level evaluation provides a comprehensive framework to assess the long-term performance, environmental impact, and techno-economic viability of emerging PV technologies, reinforcing the strategic relevance of these projects for the future deployment of sustainable photovoltaic solutions.

EPFL PV-Lab
Antonin Faes

EPFL PV-lab IEM NEUCHATEL

In 2025, the EPFL Photovoltaics and Thin-Film Electronics Laboratory (PV-Lab) continued to cement its role as a global leader in photovoltaic research and innovation, with world efficiency and stability records of perovskite and tandem solar cells, multiple high-impact achievements spanning grants, awards, modular PV advancements, 4 PhD graduations, and international conference recognition.

A major highlight was the European Research Council (ERC) Synergy Grant awarded to the "Ultimate PV project" led by Prof. Christophe Ballif, Prof. Stefan Glunz (University of Freiburg) and Prof. Stéphane Collin (CNRS). This prestigious award, part of a competitive slate of Synergy Grants, supports ambitious, interdisciplinary efforts to tackle key challenges in next-generation photovoltaics.

The lab's researchers also secured other notable recognitions in 2025. Dr. Christian Wolff received the Zeno Karl Schindler Award for his seminal contributions to perovskite and perovskite–silicon tandem solar cells. His work underpinned the first demonstration of tandem devices surpassing 30% efficiency, including world-record triple-junction cells and stable perovskite devices — crucial steps toward affordable, high-efficiency PV beyond standard silicon technologies.

EPFL PV-Lab
Antonin Faes

At the European Photovoltaic Solar Energy Conference (EU PVSEC 2025) in Bilbao, PV-Lab researchers received top honours: Dr. Umang Desai won a Best Poster Award for work on lightweight, glass-free coloured PV modules and large-format module reliability monitoring. Presentations by PhD graduates Hugo Quest and Kerem Artuk were also highlighted among the conference's significant contributions.

On the research front, PV-Lab published advances in perovskite–TOPCon tandem solar cells, achieving over 31% efficiency on front-textured devices, positioning this architecture as a scalable alternative to silicon heterojunction tandems. They also reported progress in automating and accelerating perovskite optimisation via novel tools like HITSTA and robotic ink mixing, enabling standardised, high-throughput stability and degradation studies.

Collectively, these achievements illustrate PV-Lab's multifaceted impact in 2025: securing major research funding, winning prestigious awards, advancing tandem and module technologies, and achieving peer recognition at major international forums — all contributing toward high-efficiency, durable, and scalable solar energy solutions for the energy transition.

Fraunhofer ISE
Simon Philipps

At the Fraunhofer Institute for Solar Energy Systems ISE, more than 1,300 employees conduct research to advance the energy transition through technologically viable solutions developed via high-quality scientific work, industry collaboration, and spin-offs. In 2025, the institute achieved several notable milestones across its broad research portfolio.

One major activity involves monitoring the status of Germany's energy transition. In 2025, researchers found that renewables accounted for 55.9% of Germany's net public electricity generation. Photovoltaics ranked second after wind, increasing its output by 21% and surpassing lignite for the first time. Fraunhofer ISE also developed the first method for quantifying PV self-consumption in Germany. While self-consumption was negligible until 2009 due to higher feed-in tariffs, economic incentives and sector coupling have since driven rapid growth—from 0.25 TWh in 2012 to 5.57 TWh in 2022 and reaching 12.28 TWh in 2024.

In technical PV research, several achievements stood out. An international team from KAUST, the University of Freiburg, and Fraunhofer ISE made significant progress toward industrializing perovskite-silicon tandem solar cells. They demonstrated that perovskite passivation is compatible with textured silicon bottom cells featuring large pyramids (the current industrial standard) and discovered that passivation influences the entire perovskite layer, enabling further efficiency gains.

Fraunhofer ISE
Simon Philipps

Fraunhofer ISE also established a pilot production line for PV roof tiles at its Module-TEC facility in Freiburg. This flexible, automated line enables project partner Freesuns, a Swiss solar roof manufacturer, to produce its new matrix-shingle roof tiles at pilot scale before mass production, with a planned output of 4,000 tiles.

Additionally, institute scientists developed a contactless method to measure the performance of back-contacted solar cells directly on production lines. By eliminating physical contact, the technique reduces measurement time, increases throughput, prevents mechanical stress, and lowers maintenance costs.

Finally, by analysing over 70,000 PV module power measurements conducted at CalLab PV Modules since 2012, researchers identified a trend: while module performance measured in the lab exceeded manufacturer claims until 2016, a negative discrepancy grew between 2020 and 2023, averaging –1.3%. Data from 2024 indicates a slight recovery.

Helmholtz-Zentrum Berlin
Natalia Maticiuc & Iver Lauermann

The Solar Energy Division of Helmholtz-Zentrum Berlin (HZB) develops advanced photovoltaic technologies, focusing on perovskite-based solar cells, inorganic thin-film technologies, and silicon photovoltaics. Research spans the full value chain, from materials and cell design to module fabrication, encapsulation, and device lifetime assessment, supported by advanced characterisation at the BESSY II synchrotron.

In 2025, HZB advanced efficiency, stability, reliability, and scalability of next-generation PV technologies, with a strong focus on perovskite and tandem solar cells under realistic conditions. Long-term outdoor studies showed that encapsulated perovskites can operate over multiple years, with seasonal performance variations rather than rapid intrinsic degradation (Remec et al., Adv. Energy Mater. 2025). Outdoor testing of perovskite–CIGSe tandems confirmed the power-output advantage of tandem architectures while highlighting the importance of long-term stability (Farias-Basulto et al., Adv. Energy Sustain. Res. 2025). Extended studies identified thermal stress as a key degradation driver and proposed strategies to improve lifetimes through enhanced crystallinity and interlayer stress mitigation (Wu et al., Nat. Rev. Mater., 2025).

Helmholtz-Zentrum Berlin
Natalia Maticiuc & Iver Lauermann

HZB Helmholtz Zentrum Berlin

HZB addressed mechanical and interfacial failure modes, identifying thermomechanical delamination as a critical degradation pathway and providing practical encapsulation guidance to improve durability (Emery et al., Prog. Photovolt. 2025).). Mechanistic studies clarified how light-induced halide segregation drives chemical decomposition in hybrid perovskites, while fully inorganic compositions showed enhanced resistance. Forward-bias, no-light accelerated aging protocols enabled lab tests that mimic outdoor ion-migration effects (Erdil et al., ACS Energy Lett. 2025).

High-efficiency tandem technologies were further demonstrated, with a CsCl seed layer enabling ~30% efficient perovskite–silicon tandems on textured silicon (Škorjanc et al., arXiv 2025). Complementary device physics and process optimiszation reinforced HZB's leadership in scalable, high-performance devices. Ambient processability advances included environmentally benign perovskite inks with tailored rheology for slot-die deposition, supporting uniform, glove-box-free film formation and roll-to-roll scalable processing (Florez et al, Adv. Energy Sustain. Res., 2025).

HZB also strengthened digital infrastructure for PV research data, implementing FAIR principles through the Nomad database and PV-specific schemas. These enable standardised, machine-readable storage, analysis, and sharing of experimental data, supporting reproducibility, machine learning, and cross-project comparisons. Combined with experimental and scalability advances, this positions HZB to accelerate innovation, reproducibility, and industrial translation of next-generation photovoltaic technologies.

IFE - Institute for Energy Technology
Rune Søndenå

After a few challenging years during which the upstream PV industry in Norway closed, the IFE successfully adapted to the new reality by increasing its focus on European partners and projects. In 2025, IFE participated in a series of European projects.

In 2025, IFE coordinated three large Horizon Europe projects on photovoltaics: SuRE, RETRIEVE, and EMPOWER. SuRE focuses on improving the sustainability, reliability, and efficiency of floating PV. The three leading European floating PV technologies will be improved with respect to design, sustainability, and competitiveness. RETRIEVE will increase the circularity and minimise the environmental impact of the PV industry by promoting recycling technologies for the different elements of a solar module. Closed- loop recycling of  glass and silicon will be demonstrated, while solutions for metal recovery and polymer valorisation will be developed. Digitalisation of the PV recycling industry will be supported by the development of a digital product passport framework. EMPOWER, jointly funded by Horizon Europe and SERI, aims to secure a robust European PV industry by focusing on cost efficiency. With 23 partners, this project will demonstrate disruptive innovations across the entire value chain, e.g. next-generation epitaxially grown silicon wafers, laser processing and edge-passivation, low-cost metallisation, high- throughput interconnection solutions and lamination processes.

IFE - Institute for Energy Technology
Rune Søndenå

In addition, a Digital Platform Core will support the implementation of automation and quality control for improved production efficiency. IFE plays a key role in the CETP NordStorm project, working closely with leading companies specialising in electrically conductive adhesives (ECA) to advance the development and application of next- generation high-performance ECAs that meet the demanding connectivity requirements of future high- efficiency PV modules.

IFE also participates in the EU REFINE project, integrating solar energy into hydrogen production technologies and exploring innovative pathways for renewable, low carbon green hydrogen. IFE is also hosts the national research centre for solar power (FME-SOLAR) in Norway, jointly funded by the Research Council of Norway and its many partners across the research, industry, and public sector. FME-SOLAR will provide competence and R&D targeting the main challenges associated with the growth of the PV implementation, with a special focus on integration, implementation, and operation of PV in Nordic conditions.

imec and Hasselt University
Ivan Gordon

**New Test Field for Integrated Solar Cells Opens in Genk, Belgium**

In 2025, Hasselt University, imec, and Soltech inaugurated a 55-acre test field at Thor Park in Genk, dedicated to freestanding structures with integrated solar cells, such as canopies and noise barriers. The project is part of the IN2PV investment initiative, supported by the European Regional Development Fund (ERDF). Researchers are experimenting with a variety of applications, including vertical walls, noise barriers, parking lot canopies, and agricultural solar structures (agri-PV).

The test field provides a controlled environment to trial new technologies without lengthy permitting procedures. The focus is on solar cells that are integrated directly into building materials or structures, rather than traditional standalone panels.

**Workshops on Advanced Photovoltaic Technologies**

Imec, in collaboration with Hasselt University, organized three workshops in 2025 focused on emerging PV technologies:

- The 5th TandemPV Workshop in Hasselt (May 13–15)
- The 16th ISOS Workshop in Genk (September 29–October 1)
- The 2nd BecomePV Workshop in Brussels (December 2–3), in collaboration with EERA JPPV

imec and Hasselt University
Ivan Gordon

IMO-IMOMEC
UHASSELT imec

**Solar Energy Plan for the Einstein Telescope**

The Einstein Telescope (ET) requires a stable, quiet, and sustainable energy supply to maintain its extreme sensitivity. Solar energy, combined with battery storage and DC transmission, offers a noise-free and efficient solution. The ET's annual energy consumption is estimated at 100 GWh, with 80% potentially supplied by one or two large local solar farms, involving community participation. The remaining 20% could be met through building-integrated and nature-integrated PV, supporting multifunctional, environmentally respectful systems in areas near Natura 2000 sites.

**Foton Project: Sunlight-Driven Chemistry**

Within the Foton project, imec is developing a PV-integrated electrolyzer for water splitting. A 20 × 20 $cm^2$ alkaline electrolyzer with a 5 × 5 $cm^2$ catalyst layer was designed and coupled with a flexible CIGS PV module producing up to 4 V and 400 mA. Ni-based catalysts and custom silicon modules from SOLTECH are used. Membrane-less electrolyzers are being explored to lower costs and improve durability. Additionally, standalone photoelectrochemical (PEC) systems are under development using advanced materials from UHasselt and EnergyVille, including $CuInGaS_2$ and $BiVO_4$, to optimize solar-to-hydrogen conversion.

This comprehensive effort combines applied research, sustainability, and advanced technological development in solar energy.

INL - International Iberian Nanotechnology Laboratory
Sascha Sadewasser

INL continued the coordination of two EU- level projects, the Research and Innovation Action Hi-BITS, in which the consortium develops bifacial Cu(In,Ga)Se2 (CIGS) solar cells based on a new device architecture on transparent back contacts. In addition, in the CETP project TRANSMIT, INL coordinates the development of micro-structured semi-transparent CIGS and perovskite solar cells.

In 2025, INL installed a Midsummer deposition system UNO for research on CIGS solar cells.

Institut Photovoltaïque d'Île-de-France (IPVF)
Pere Roca i Cabarrocas

In 2025, IPVF achieved a major milestone in bifacial perovskite photovoltaic technology, demonstrating its unique capacity to bridge laboratory research with industrial-scale manufacturing. Its teams successfully developed bifacial perovskite devices, reaching 18.1% power conversion efficiency on 2 cm × 2 cm mini-modules, alongside 16.8% efficiency on 10 cm × 10 cm, results that represent a decisive step toward industrialisation.

This breakthrough was enabled by a novel passivation strategy at the interface between the perovskite layer and the n-type contact. The optimal molecular combination, initially identified through fundamental research, was seamlessly transferred to the development programmes focused on process optimisation and industrial compatibility. Devices were first fabricated using spin coating, then successfully scaled using slot-die coating under ambient conditions, enhanced by vacuum quenching to improve layer quality. The wide-bandgap hybrid perovskite technology employed offers high compatibility with tandem configurations.

Building on these results, IPVF is now scaling up to 60 cm × 30 cm semi-transparent perovskite devices designed for integration with silicon modules in a four-terminal, two-wire (4T2W) perovskite-silicon tandem architecture. This work will be carried out on a new prototyping line scheduled for commissioning in early 2026, developed in partnership with French manufacturer Voltec Solar as part of the STaFF project (Solar Tandem for Future).

Institut Photovoltaïque d'Île-de-France (IPVF)
Pere Roca i Cabarrocas

To support this scaling up, IPVF has reinforced its characterisation capabilities with the installation of a state-of-the-art solar simulator featuring advanced electroluminescence analysis, supplied by Ecoprogetti, enabling precise testing of perovskite cells and modules.

These achievements reflect IPVF's mission as a European center of excellence: combining world-class research with industrial expertise to accelerate the deployment of next-generation photovoltaic technologies and strengthen Europe's position in the global solar energy landscape.

NIS Centre for Nanomaterials for Industry and Sustainability,
Department of Chemistry and Physics - University of Torino
Claudia Barolo

At the University of Torino, the past year was marked by intense and productive activity, with substantial progress across multiple research projects and strong international visibility through conferences and high-impact publications in the field of photovoltaics (PV).

Three major projects were successfully launched. The HORIZON-EIC-2024 Pathfinder Open BioSinFin project aims to develop a bioinspired coating to enhance silicon solar cell efficiency. The HORIZON EUROPE – European Innovation Council project "JUMP INTO SPACE" focuses on flexible, lightweight multi-junction solar cells and modules for efficient light harvesting in space applications; during its first year, key scientific and technological milestones were achieved, establishing a solid foundation for future developments. In parallel, the first year of the national PTR 25–27 Innovative, Efficient, and Sustainable Integrated Photovoltaic project was completed, strengthening research activities and infrastructure in the PV sector.

Among ongoing initiatives, the CANVAS project (New Concepts, Materials, and Technologies for the Integration of Photovoltaics into Buildings in a Distributed Generation Scenario) entered its third year. This phase is particularly relevant as it includes the fabrication and demonstration of transparent photovoltaic devices, advancing multifunctional and aesthetically integrated energy solutions. Additionally, a new national PRIN project dedicated to photovoltaics officially started, further reinforcing national research efforts and collaborations.

NIS Centre for Nanomaterials for Industry and Sustainability, Department of Chemistry and Physics - University of Torino
Claudia Barolo

At the European level, several MSCA proposals, including COFUND and Innovative Training Network schemes, were submitted within the UNITA Alliance, with the University of Turin (UNITO) acting as coordinator. These energy-focused proposals underline UNITO's strategic role in the alliance and its commitment to advanced training in PV research.

International visibility remained strong. Prof. Claudia Barolo co-organized the 17th International Conference on Hybrid and Organic Photovoltaics (HOPV 2025, Rome, May 12–14) and was invited speaker at IMRC 2025 (Cancun) and Pacifichem 2025 (Honolulu). Prof. Nadia Barbero also participated as an iInvited sSpeaker at HOPV 2025.

Research productivity was high, with over 20 peer-reviewed publications on photovoltaic topics, confirming the group's strong scientific impact and visibility.

TNO Solar
Jan Kroon

TNO's research program on Solar is structured around three core propositions:

1. **Solar Device Technology**

TNO develops next generation solar devices with a strong focus on crystalline silicon (c Si) heterojunction solar cells and perovskite solar cells for both single- junction and tandem architectures. Key research topics include the scalability and long-term stability of perovskite technologies.

TNO participates in numerous European Horizon research projects and has made significant progress in developing advanced, scalable manufacturing routes for perovskite solar cells and modules. These routes emphasise low temperature, low cost, roll to roll compatible processing. The resulting innovations reinforce TNO's position in the industrialiszation of perovskite technology and support broader commercialisation pathways.

2. **Solar Module and Sustainability**

Within this proposition, TNO develops advanced module architectures based on crystalline silicon, using innovative interconnection technologies, circular design principles, and mass customiszation approaches.

TNO Solar
Jan Kroon

TNO innovation for life

A major milestone is the realisation of a full-size bifacial back contact module with very low cell- to- module (CTM) losses and bifocality factors above 80%, achieved within the Horizon IBC4EU project.

TNO also developed a flexible mass customisation line for processing semi-fabricated laminates. This enables integration into various PV applications, such as Building Integrated PV (BIPV), Infrastructure Integrated PV, and Vehicle Integrated PV (VIPV). Significant progress in this field was achieved within the Horizon MC2.0 project, coordinated by TNO.

3. **Solar Application and System Integration**

TNO develops technologies and models that accelerate the energy transition and help European and Dutch industries reestablish solar manufacturing capabilities in Europe. The work spans a wide variety of applications, including VIPV, BIPV, Agri PV, offshore and floating PV systems, and the digitalisation of PV.

TNO played a key role in introducing eco labelling for solar parks in the Netherlands by applying advanced light management models. Additionally, TNO has been highly active in the development of offshore solar solutions integrated into offshore wind parks, supporting start-ups and addressing the associated R&D challenges. TNO is also developing and applying Physics Informed Machine Learning models that can unlock new information and understanding about PV performance. This was applied for BIPV and Floating PV data from existing plants.

University of Milano-Bicocca
Simona Binetti

Throughout 2025, the team's scientific milestones focused on the development of next-generation thin-film photovoltaic technologies, aiming to bridge the gap between laboratory-scale efficiency and industrial scalability. Research activities were structured around three fundamental pillars: the optimization of kesterite-based absorbers, the advancement of semi-transparent perovskite cells, and the realization of flexible tandem devices.

**Optimization of Kesterite and Other Earth-Abundant Materials**
A major milestone was the development of the first inkjet-printed flexible kesterite (CZTSSe) solar cell. By transitioning from traditional spin-coating to drop-on-demand inkjet printing techniques, the team achieved efficiencies exceeding 10%, representing a 15–20% improvement over corresponding spin-coated reference devices. This result addresses the scalability limitations and precursor waste typically associated with kesterite synthesis. By producing a more homogeneous and compact crystalline material through printing, the researchers demonstrated a sustainable pathway for the industrial scale-up of flexible integrated photovoltaics.

In parallel, $Cu_2MnSnS_4$ (CMTS) was explored as a non-toxic, earth-abundant alternative for solar energy harvesting. The team established a new efficiency record of 0.97% for wet-prepared CMTS, achieved through fine-tuned post-deposition treatments and slow-cooling strategies.

University of Milano-Bicocca
Simona Binetti

Beyond the nhis work provided a deep understanding of intra-gap defects, magnetic orders, and semimetallic character that currently limit the material, defining a clear roadmap for future defect passivation and controlled doping studies.

**Engineering Transparency and Tandem Synergy**

In semi-transparent perovskite solar cells (ST-PSCs), the researchers achieved a landmark Light Utilization Efficiency (LUE) of 1.00% by engineering a novel electron transport bilayer using ALD-deposited $TiO_2$ combined with $SnO_2$. This approach balanced high average visible transmittance (7.49%) with a power conversion efficiency of 13.41%, while optimizing the morphology of $CsFAPbI_3$ thin films to ensure transparency without sacrificing performance.

Finally, 4-terminal (4T) kesterite/perovskite tandem solar cells were successfully fabricated on flexible substrates. By integrating Na-doped and Ag-alloyed CZTSSe bottom cells with high-efficiency semi-transparent perovskite top cells, the team achieved efficiencies exceeding 22% on rigid substrates and 20% on flexible foils. These lightweight and mechanically flexible technologies offer significant potential for next-generation applications, including product-integrated (PIPV), building-integrated (BIPV), vehicle-integrated photovoltaics (VIPV), and wearable devices.

University of Padova
Matteo Meneghini

In 2025, the research group at the University of Padova achieved significant advances across multiple areas of photovoltaic science and technology, strengthening both fundamental understanding and applied innovation in solar energy systems. A major focus of the work was the investigation of surface recombination mechanisms in silicon solar cells. Through experimental analysis and modelling, the researchers studied carrier losses at interfaces, contributing to improved strategies for passivation and efficiency enhancement in crystalline silicon devices.

University of Padova also made substantial progress in the modelling of conduction processes in silicon heterojunction solar cells using TCAD simulations. These activities enabled a deeper understanding of charge transport, band alignment, and interface effects, providing valuable insights for device optimisation and supporting the design of next-generation high-efficiency architectures.

Another key research direction addressed the stability of emerging photovoltaic technologies. They developed and applied models to describe degradation mechanisms in perovskite solar cells, linking material properties and environmental stressors to performance losses over time. In parallel, the research group conducted detailed analyses of silicon photovoltaic modules subjected to hail impact testing, assessing mechanical damage and its consequences on electrical performance and long-term reliability.

University of Padova
Matteo Meneghini



Finally, the group explored innovative materials for advanced photovoltaic applications through the study of thin plastic lamination solutions for flexible silicon photovoltaics. This work demonstrated the potential of lightweight, mechanically robust encapsulation approaches that enable new form factors while maintaining device performance.

The research group studied and developed photovoltaic technologies to enable energy autonomy in different contexts: perovskite solar cells support optical wireless power transfer for underwater sensor networks; PV generation supplies net-zero electricity for LED-driven microalgae photobioreactors at container and industrial scale; vehicle headlight energy harvesting complements ultra-low-power optical modulation for passive roadside sensing nodes.

Together, these achievements reflect a comprehensive research effort spanning materials, devices, modelling, and reliability, reinforcing the group’s contribution to the advancement of photovoltaic technologies in 2025.

University of Rome Tor Vergata - Centre for Hybrid and Organic Solar Energy (CHOSE-UNITOV)
Aldo Di Carlo

In 2025, the Centre for Hybrid and Organic Solar Energy of the University of Rome Tor Vergata (CHOSE-UNITOV) significantly strengthened its leadership in perovskite and emerging photovoltaic technologies, spanning materials, devices, modules, and system-level integration. Major progress was achieved in efficiency enhancement, with multiple studies reporting material and architectural strategies to improve power conversion efficiencies in both cells and modules.

A second key milestone was the advancement of stability and reliability, a critical barrier to commercialiszation. CHOSE-UNITOV delivered landmark results on device durability under harsh conditions, including humidity, thermal stress, reverse bias, ioniszing particle irradiation, and underwater operation. The development of innovative encapsulation strategies, defect passivation approaches, and robust electrode architectures led to substantial improvements in operational lifetimes (T80 > 1000 h in several cases), positioning CHOSE-UNITOV at the forefront of stability-oriented perovskite research. In parallel, 2025 marked a decisive step toward scalability and industrial relevance. CHOSE-UNITOV researchers demonstrated high-efficiency large-area modules (up to 0.73 $m^2$ panels) with geometric fill factors above 96%, while also proposing standardised frameworks for process control, reporting, and stage-gate upscaling. These contributions directly support reproducibility, automation, and technology readiness level advancement within the European PV ecosystem.

University of Rome Tor Vergata - Centre for Hybrid and Organic Solar Energy (CHOSE-UNITOV)
Aldo Di Carlo

CHOSE-UNITOV expanded its impact in energy harvesting and storage, including thermoelectric, supercapacitors, photo capacitors, and multifunctional polymer nanocomposites. Notably, integrated energy solutions for low-light and indoor applications were demonstrated, enabling self-powered IoT and edge-computing systems without batteries—an emerging priority for sustainable digitalisation. In this field, CHOSE-UNITOV researchers co-authored two international perspective papers in Joule and Nature Reviews Clean Technology on promises and challenges of indoor photovoltaics and its testing, as well as presenting the first module with perovskite inspired materials for indoor photovoltaics. CHOSE-UNITOV also demonstrated spill over in a field where light also produces electrical output from organic PV materials: i.e. artificial vision research.

Finally, CHOSE-UNITOV researchers reinforced its commitment to sustainability and environmental responsibility, through green solvent processing, lead-free and low-toxicity materials, carbon-based electrodes, and life-cycle–aware device designs. Collectively, these milestones confirm CHOSE-UNITOV's role as a key contributor to EERA objectives, bridging fundamental science, applied engineering, and pre-industrial deployment of next-generation renewable energy technologies.

In 2025, CHOSE-UNITOV also organised the Indoor Photovoltaics Conference (IPVC-2), the Hybrid and Organic Photovoltaics Conference (HOPV 2025), and the Perovskite Evaporation Conference (PEC-2025). It also took part in several EU- funded projects as well as national projects including Mission Innovation.

Utrecht University
Sara Golroodbari

In 2025, the photovoltaics research group reached several important milestones that strengthened the scientific and operational foundations of solar energy systems across forecasting, storage, and emerging photovoltaic applications.

A key milestone was the development of an operational short-term solar irradiance forecasting framework based on all-sky imagery and hybrid artificial intelligence techniques. This work introduced a weather-adaptive methodology combining superpixel-based cloud detection, SVM–CNN architectures, and Kalman filtering to achieve accurate forecasts up to 30 minutes ahead while maintaining low computational complexity. The framework demonstrated improved performance under rapidly changing sky conditions and was explicitly designed for real-time grid integration and edge-device deployment, supporting higher photovoltaic penetration and more effective use of flexibility assets such as batteries [1].

Another major achievement in 2025 was the advancement of thermal modelling for floating photovoltaic (FPV) systems. They developed a scalable, physics-based approach that integrates computational fluid dynamics (CFD)–derived wind decay functions into a dynamic heat transfer model. This allowed spatial and temporal temperature variations across large FPV arrays to be captured more accurately than with conventional steady-state models.

Utrecht University
Sara Golroodbari

Validation against field measurements showed strong agreement across daily and seasonal timescales, providing a robust basis for improved FPV performance prediction, degradation assessment, and environmental impact evaluation [2].

In parallel, PhD researchers of the Utrecht University published a comprehensive review on battery energy storage system optimisation in the built environment. This work provided a structured synthesis of battery applications in residential buildings, energy communities, and urban systems, with particular emphasis on linking degradation modelling and multi-objective optimisation. By situating these technical approaches within the European regulatory and market context, the review offers a unifying framework that connects academic research with real-world deployment challenges, such as grid congestion management and urban flexibility provision [3].

Collectively, these milestones position their 2025 research at the intersection of solar forecasting, battery optimisation, and system-level photovoltaic modelling. They establish a strong platform for future research on integrated PV–battery control strategies, grid-responsive energy systems, and the deployment of advanced floating and urban PV technologies.

Utrecht University
Wilfried van Sark

A novel solar forecasting framework has been developed providing accurate irradiance forecasts up to 30 min ahead while maintaining real-time computational efficiency. The operational framework integrates advanced sky image analysis with a hybrid AI architecture and Kalman filtering optimisation. Key technical innovations include (1) superpixel-based cloud detection using Simple Linear Iterative Clustering (SLIC) for precise atmospheric characterisation and (2) a hybrid Support Vector Machine–Convolutional Neural Network (SVM–CNN) model with Kalman filtering for Clear Sky Index estimation across diverse weather conditions. A weather-adaptive clustering module dynamically adjusts forecasting strategies across five sky conditions, while multi-frequency

A model was developed with the purpose of demonstrating that intermittent renewable energy sources can be transformed into firm power, which can power Europe around the clock and throughout the year. The results indicate that overbuilding and curtailment of renewables significantly lower system costs and includes battery storage. Careful balancing of renewables and storage capacity is required to enable an economically attractive solution to a renewables-

A study was presented on a scalable methodology for accurate thermal modelling of floating photovoltaic systems. It integrates computational fluid dynamics (CFD) derived wind decay functions into a dynamic heat transfer model to capture regional variations in module cooling.

EERA
European Energy Research Alliance
Photovoltaic Solar Energy

Utrecht University
Wilfried van Sark

Utrecht University

The approach is applied to a large FPV installation in the Netherlands, divided into multiple zones. The model incorporates convective, conductive, and radiative heat exchanges to calculate front, cell, and back temperatures. Validation against measured module temperatures over multiple seasons shows strong agreement, under varying ambient conditions across daily and seasonal timescales. When compared with steady-state models such as Faiman and PVsyst, the proposed model demonstrates improved accuracy and adaptability to transient meteorological changes. This work has been published in Renewable Energy.

EERA
European Energy Research Alliance
Photovoltaic Solar Energy

# EERA Joint Programme on Photovoltaic Solar Energy

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