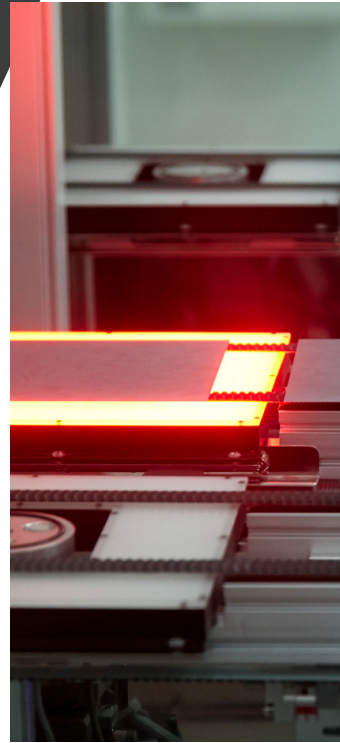
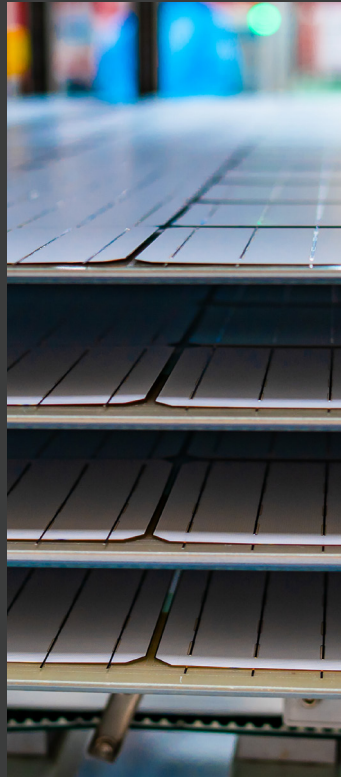


Shaping the future of solar energy with tandem technology



pepperoni-project.eu



Newsletter #3

Welcome to the third issue of the newsletter of the PEPPERONI project!

“This is the first report of tandem modules passing these stress tests, considering tandem-specific restrictions on power measurement, so this is truly a pivotal moment for tandem solar technology,” said Danielle Merfeld, Global Chief Technology Officer at Qcells.* *“Qcells’ breakthrough marks a critical step towards commercial readiness.”*

In this edition, we explore the latest trends shaping the solar energy sector, highlight key technical milestones, including recent breakthroughs in tandem module stability, and share new scientific publications from the PEPPERONI consortium. Also, don’t miss the Insights from the Lab section, where we highlight partners’ expertise and infrastructure.

Join us as we take a closer look at the developments paving the way for durable, scalable, and high-efficiency tandem solar modules in Europe and beyond.

- p.1** Developments
- p.2** Industry insights
- p.3** Project insights
- p.4** Technology advances
- p.5** Inside the Lab

*ref.: [Qcells press release](#), May 14 2025

Developments

how is the PV market doing in 2025?

Consolidation and competition

The photovoltaic (PV) sector enters the second half of the decade in a paradoxical state, booming global installations, with the European Union on track to install 70 GW of solar energy capacity, paired with unprecedented pressure on manufacturers. As presented at Intersolar Europe 2025, major producers are navigating a landscape marked by intense pricing competition, growing inventories, and looming industry consolidation.

Tandem technology, promise meets practicality

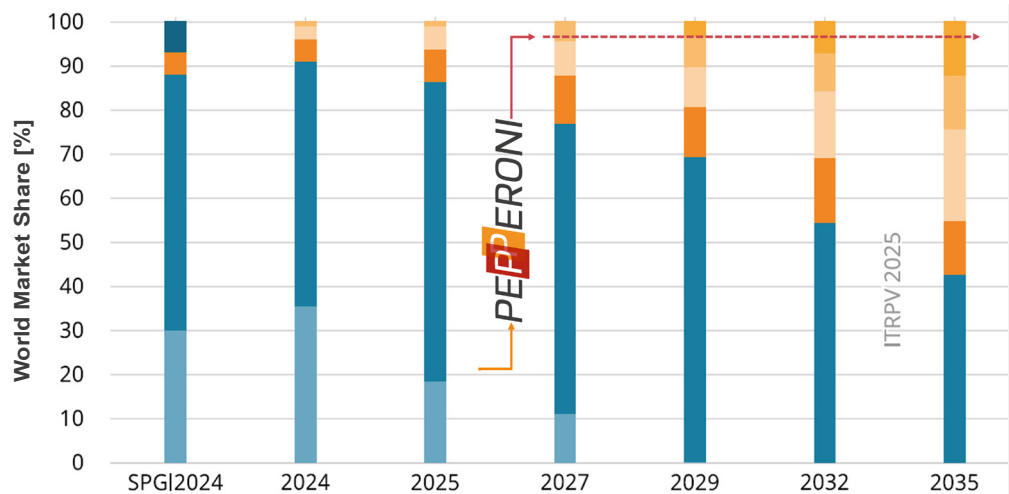
Perovskite/silicon tandem cells, long hailed as the next breakthrough in module performance, are now at a crossroads between lab promise and industrial adoption. While small-scale demonstrations and pilot lines (including those within PEPPERONI) have achieved >28% cell efficiency and promising durability, mass-market uptake remains constrained by stability, manufacturing readiness and scaling costs.

what does it mean for PEPPERONI?

The shifting PV landscape in 2025 reinforces the strategic relevance of the PEPPERONI project. As the industry faces tight margins and hesitates to scale up new technologies, PEPPERONI directly targets the key roadblocks to commercialising tandem PV.

Different cell technologies

- PERC cells
- TOPCon double sided contact cells
- Silicon heterojunction (SHJ) double sided contact cells
- TOPCon-based back contact cells (TBC)
- SHJ-based back contact cells (HBC)
- Si-based tandem cells
- xBC



Ref: ITRPV, 2025. "Market shares for different cell technologies."
<https://www.vdma.org/international-technology-roadmap-photovoltaic>

High-efficiency to counter market saturation:

The ongoing oversupply and price compression make it increasingly difficult for conventional PV products to remain profitable. PEPPERONI addresses this challenge by advancing perovskite/silicon tandem technologies that promise to increase power output per square meter, a key metric for restoring economic viability and reducing Levelised Cost of Electricity (LCOE), especially in space-constrained installations, like rooftops.

From lab to line:

PEPPERONI works on scalable processes, pilot line integration, and reducing cell-to-module (CTM) losses, pushing the technology toward technology readiness level (TRL) of 7, which lays the ground work for future mass deployment.

Building confidence through reliability:

Industry hesitation around tandem PV adoption is also rooted in concerns about long-term stability, accurate and comparable performance testing, and environmental impact. PEPPERONI develops stable cells and durable encapsulation, standardisation protocols, field validation methods to meet certification demands and collects valuable indoor and outdoor data of relevant tandem devices.

A European answer to global consolidation:

With consolidation reshaping global supply, PEPPERONI's strong European consortium contributes to domestic innovation capacity, aligned with the EU's Net-Zero Industry Act goals.



what do the recent records say?

Reflecting momentum in the field, the latest [Green's Solar Cell Efficiency Tables](#) highlights a surge in new tandem records, including Qcells's certified **28.6% efficiency** for its perovskite/silicon tandem cell. This milestone underpins the project's focus on scalable, high-performance tandem technologies with more achievements to share.

Paving the way for the commercialisation of high-efficiency solar technology

Qcells, a global leader in solar energy solutions and a core partner in the PEPPERONI project has achieved a major step towards commercialising tandem solar modules. The company has successfully completed a series of rigorous stress tests on its perovskite/silicon tandem modules, verified independently by TÜV Rheinland. These tests meet criteria defined in, both, International Electrotechnical Commission (IEC) and Underwriters Laboratories (UL) certification standards, and were performed following tandem-specific power measurement protocols, a first in the industry.

The graphic features a dark blue background with a large, stylized 'M10' logo in the center, representing the module size. The Qcells logo is in the top right corner. The main text is white and reads: 'Qcells Achieves Key Tandem Solar Module Stability Milestone'. Below this is a quote from Fabian Fertig, Head of Tandem R&D at Qcells Germany, praising the achievement based on their in-house developed perovskite and Q.ANTUM silicon technologies.

Qcells Achieves Key Tandem Solar Module Stability Milestone

“Qcells is pleased to announce this outstanding stability achievement based on our in-house developed perovskite technology as a top cell, and cost-efficient Q.ANTUM silicon technology as a bottom cell,”
said Fabian Fertig,
Head of Tandem R&D at Qcells Germany

Enabling reliable, sustainable tandem deployment

The core of this latest achievement by Qcells involves successfully passing the most critical stress tests for solar cell reliability according to International Standards IEC 61215-2:2021 and UL 61215-2:2021. These include the UV preconditioning test for 15kWh/m² (MQT10; UV15), thermal cycling test for 200 cycles (MQT11; TC200), humidity-freeze test for 10 cycles (MQT12; HF10), and damp heat test for 1000h (MQT13; DH1000). These stress tests have been successfully passed by fulfilling the tandem-specific requirements for power measurements as specified in International Standard IEC TS 60904-1-1 for multi-junction modules. The tested modules were manufactured at Qcells' R&D pilot line in Bitterfeld-Wolfen (Germany), using industry-compatible methods and full-area M10 substrates for solar cell fabrication.

Importance of public-private collaboration and EU support

Reaching certified stability benchmarks for new solar technologies like tandem perovskite/silicon modules is a highly challenging task, but one that can be accelerated through joint efforts of industry and academia. PEPPERONI brings together leading research institutions, technology developers and manufacturing experts to integrate innovation across the full value chain. This reflects the strength of pan-European collaboration, supported by the EU, in fast-tracking research-to-industry transitions. Such cooperation is essential not only for technical success but also for ensuring that European innovation translates into industrial capacity, market adoption, and global leadership, core priorities of the EU's clean energy strategy.

[Read more](#)

what does Fabian Fertig say?

What does this stability milestone mean for real-world durability and industry certification?

This achievement shows that perovskite/silicon tandem modules can withstand the same rigorous environmental stress testing standards as currently deployed PV technologies. Successfully completing UV, thermal cycling, humidity-freeze, and damp heat testing demonstrates that the technology exhibits a solid stability. Importantly, the performed testing fulfilled tandem-specific power measurement requirements according to IEC TS 60904-1-1, an industry first. In order to be ready for product launch, we need to stress test beyond current IEC standards, and prove long-term stability in field installations.

How does the cell and module design used in the test compare to current lab-scale tandem cells and modules?

The devices used in the IEC tests have been manufactured within the Qcells R&D pilot line by exclusively using processes feasible for mass production. In contrast, in a lab environment typically several processes are used that cannot be scaled to high throughputs. The cell and module structures of the tested devices are based on a potential future commercial product design. That means, cell and module dimensions, as well as materials and material properties used in the fabrication of these devices, are selected in alignment with future product properties. This is typically not the case for prototypes fabricated in a lab-scale environment, where device dimensions and material ratios are typically not optimized for future commercial products.



Fabian Fertig (Qcells)

PEPPERONI technology development coordinator

Does improved moisture and heat resistance mean longer lifetimes or better warranties for future tandem products?

The target of tandem product development at Qcells and within PEPPERONI is to at least match the warranty of existing PV products. Improving moisture and heat resistance, as demonstrated in the IEC tests, are major steps towards achieving this target. However, further development is required to close the remaining gap to the long-term reliability of existing products.

How close are these modules to market integration?

The tested modules were manufactured using Qcells' R&D pilot line that is comprised of mass-production feasible equipment and processes. Hence, once the remaining technological challenges are solved, this technology can be readily scaled to large volumes. For PEPPERONI and Europe's broader PV ambitions, this marks a critical step forward in bridging the innovation-commercialisation gap.

what are the remaining challenges?

This achievement marks a major step toward mass production readiness. However, several challenges remain that are being tackled by PEPPERONI partners:

- Different effects are observed between small and full-area cells, highlighting the need for uniformity during scaling and mass manufacturing.
- Further research on understanding relevant factors for long-term stability with respect to interconnection and encapsulation of full-size tandem modules.
- Efficiency gains at the cell level must be preserved through interconnection and encapsulation.
- Long outdoor exposure is needed to fully assess degradation under variable weather and climate conditions.
- The industry is still aligning around test protocols and measurement standards for tandem architectures.

In essence, the recent milestone de-risks the core technology, and future work will focus on achieving reliability milestones beyond IEC certification testing standards and demonstrating long-term stability in the field.

what do publications reveal?

In the previous newsletter ([Issue #2](#)), we explored the main challenges hindering the large-scale adoption of perovskite/silicon tandem PVs, like stability, durability, manufacturing, and standardisation - and how PEPPERONI is tackling them. Now, discover how recent publications from the project turn these challenges into research-driven solutions.

[Tips and Tricks for a Good Encapsulation for Perovskite-Based Solar Cells](#)

DOI: <https://doi.org/10.1002/pip.3888>

Challenges addressed: encapsulation, stability and degradation, durability.

This publication explores how different encapsulation materials and designs affect the long-term durability of perovskite solar cells, with a focus on vacuum lamination techniques that are compatible with existing PV manufacturing lines. Researchers tested various combinations of encapsulants and edge sealants, identifying trade-offs between moisture protection, thermal cycling resistance, and optical performance.

Key outcome: A polyolefin + butyl edge sealant stack showed the most promising balance, passing damp-heat testing and reducing thermomechanical failures. The study emphasizes the need for a holistic encapsulation strategy that addresses environmental stress, mechanical properties of the materials and optical constraints.

Why does it matter? It supports material selection and design rules for tandem modules to remain stable in field conditions. Particularly relevant for module designers, manufacturers and reliability engineers.

[Facile and Low-Cost Design Alternative of Spiro-OMeTAD as p-Type Semiconductor for Efficient Perovskite Solar Cells](#)

DOI: <https://doi.org/10.1002/solr.202500034>

Challenges addressed: material supply, manufacturing.

In this publication, PEPPERONI researchers present V1553, a newly developed low-cost hole transporting material (HTM) designed as an alternative to the expensive industry standard, spiro-OMeTAD. Synthesized through a simple, catalyst-free, one-step reaction using widely available reagents, V1553 enabled perovskite solar cells to reach power conversion efficiencies close to 23%.

Key outcome: The innovation not only delivers high performance but also dramatically lowers material costs, making it a promising candidate for scalable, cost-effective tandem module manufacturing.

Why does it matter? It supports efforts to streamline the bill of materials (BoM) for perovskite-based devices while maintaining industrially relevant efficiencies, key for commercial viability. Relevant mostly for PV manufacturers, material scientists and scale-up teams.

[Mimicking Outdoor Ion Migration in Perovskite Solar Cells: A Forward Bias, No-Light Accelerated Aging Approach](#)

DOI: [https://doi.org/10.1021/acsenergylett.5c00376](https://doi.org/10.1021/acseenergylett.5c00376)

Challenges addressed: stability and degradation, standardisation.

This study introduces a novel accelerated ageing protocol for perovskite solar cells (PSCs) that simulates real-world outdoor degradation. By applying a prolonged forward bias in the dark, followed by a resting phase, researchers reproduced key degradation phenomena such as ion migration, charge transport impediments, and reversible light-induced effects, closely mirroring similar effects of 20-months outdoor field data from Berlin.

Key outcome: This test method offers a simple, time-efficient tool for predicting perovskite device behaviour under seasonal climate cycles, without requiring expensive and time consuming illumination setups and testing. It opens new avenues for reliable and cost-effective stability screening of perovskite-based devices such as the PEPPERONI tandem modules.

Why does it matter? It strengthens efforts to predict, test and model device ageing, supporting accelerated development by faster qualification of materials for industrial and field deployment. Relevant especially for PV researchers, test engineers, module developers and material scientists.

[Read more](#)

In this section, we highlight the latest technology advances in the PEPPERONI project, driven by key deliverables, tangible outcomes or reports that mark progress in our research and development efforts.

D3.7 Tandem cell processed on full area wafers (M6 or M10): Three PEPPERONI project partners have been actively working on the top-cell development via different processing routes: HZB using vacuum-based perovskite-deposition methods, CSEM using solution-based and hybrid processes, and Qcells selecting one relevant process route for industrialisation. The objective of this deliverable was to demonstrate a perovskite/Si tandem solar cell with an active area >200 cm², excluding the wafer edges, an objective achieved by Qcells.

D3.8 Tandem cell with a PCE of 28%: This deliverable focused on the demonstration of full-area tandems of industrial dimensions, meaning including the full-area as in an industrial product. Partners from Qcells and CSEM made breakthroughs in the framework of PEPPERONI in this regard, demonstrating high efficiency cells of medium (CSEM) to large, industrial dimensions (Qcells). Qcells achieved the deliverable targets, with a certified PCE of 28.6% obtained with a full-area M10 tandem (full-area of 331 cm², i.e. total area measurement).

D4.2 Full-module strings: Tandem cell processed on full M6 wafers: Demonstrates the full-module strings with low PCE loss induced by the interconnection of the cells. "Full-module string" means the interconnection of a number of full-size wafers as can be used in a full-size module. In order to achieve the target, the interconnection mode has to be defined, a potential module design needs to be chosen, and the actual module fabrication process needs to be optimized to achieve the target. During process development, several different topics have been addressed by PEPPERONI partners, including wire/ cell/ alignment accuracy, wire pre-treatment, cell format compatibility, accurate curing process control, material screening as well as deposition & curing process development.

D5.5 Specifications and conceptual designs for the upgrade of the interconnection tool: Describes the specification and conceptual designs of the upgrades for the interconnection tool. This is the newest tabber stringer reference from Mondragon Assembly for low-temperature processes. These upgrades will be divided into different areas including the wire-ribbon/cell alignment accuracy improvement, wire-ribbon pre-treatment, cell format compatibility and accurate thermal process control.

D6.2 A recipe and production method defined for a modified POE: Provides an overview of the materials made and supplied by Yparex for the PEPPERONI project within work package 6, WP6. Part of this WP's work is focused on the development of an encapsulant that works with perovskite cell technology and is processable at low temperatures. Yparex develops a thermoplastic polyolefin encapsulant, processable at lower temperatures while being able to withstand loads at 105 °C. Processing at lower temperatures can be preferable for the stability of perovskite-based cells during lamination. Future work will focus on the continuous improvement of encapsulants based on the feedback loops with the PEPPERONI partners including adjustments in either the recipe or processing parameters.

D6.7 Test protocol for precursor and incoming material inspection: Describes the test protocols for inspecting precursor and incoming materials used in the production of perovskite-silicon tandem solar cells. The report explains the methods used for the quality inspection of different cell and module materials like encapsulants, precursors, and interconnection materials. Typical properties of incoming materials like thermal stability, chemical composition, viscosity, purity, shelf stability, as well as thermal and mechanical properties are monitored via different methods on a regular basis to ensure a constant high level of input material quality.

D7.2 IEC and ISOS testing results: In this deliverable, CSEM and Qcells demonstrate encapsulated perovskite/Si tandem solar cells passing the IEC 61215 test criteria for damp heat, thermal cycling, thermal cycling combined with humidity freeze and UV pre-conditioning. Tandems were shown to degrade in power by less than 5%rel in these conditions. Importantly, Qcells demonstrated the successful pass of DH1000, TC200, HF10 and UV15 IEC tests as described earlier in the newsletter. The TC test is essential for validating layer adhesion, interconnect robustness and encapsulation performance and passing TC200, among passing DH1000, HF10 and UV15 tests, is a major milestone for industrial readiness. Furthermore, CSEM and HZB conducted ISOS L light soaking tests, notably to investigate the impact of the contact materials on the operational stability of perovskite solar cells.

[Read more](#)

Helmholtz-Zentrum Berlin für Materialien und Energie (HZB) strives to achieve a climate neutral society through science and innovation by driving materials discovery, creating new sustainable technologies, and empowering the research community in realizing this goal. Therefore, researchers are developing and optimising efficient and cost-effective materials for solar cells, batteries and catalysts. These energy materials are essential components for achieving a CO₂-neutral and secure energy supply.

Testing equipment

Recently, at HZB, a new indoor light soaking rig is being set up, and new climate chambers and UV testing rigs have been installed. HZB's rooftop test field in Berlin is also continuously updated to meet the project's evolving needs. It now supports testing of full-area industrial PV modules, semi-industrial prototype mini-modules, and small-area cells. For PEPPERONI, the MPP tracking capacity has been extended to include 100 mA boards, accommodating the prototype tandem cell design. The devices are surrounded by sensors monitoring environmental parameters, such as irradiance, temperature, solar spectrum, and other weather conditions (humidity, precipitation, wind speed, etc.).

Several groups investigate materials, processes and up-scaling in order to provide a future solar cell technology being high-performing, stable and sustainable. HZB is coordinating the PEPPERONI project jointly with Qcells. The focus in its R&D contribution is on [the integration of processes for perovskite/silicon tandem cells](#), module encapsulation, and stability and yield studies by indoor testing and outdoor monitoring of such cells and modules. Therefore, new indoor testing equipment has been set up and the out door test field has been expanded.



Tandem-compatible indoor accelerated testing
Light, T, cycles (N₂/air)

Modules photo-stability
Light, T, cycles (air)

Climate chambers
DH, TC, UV, Light

what does it bring?



Carolin Ulbrich (HZB)

Group leader Outdoor Performance, PVcomB

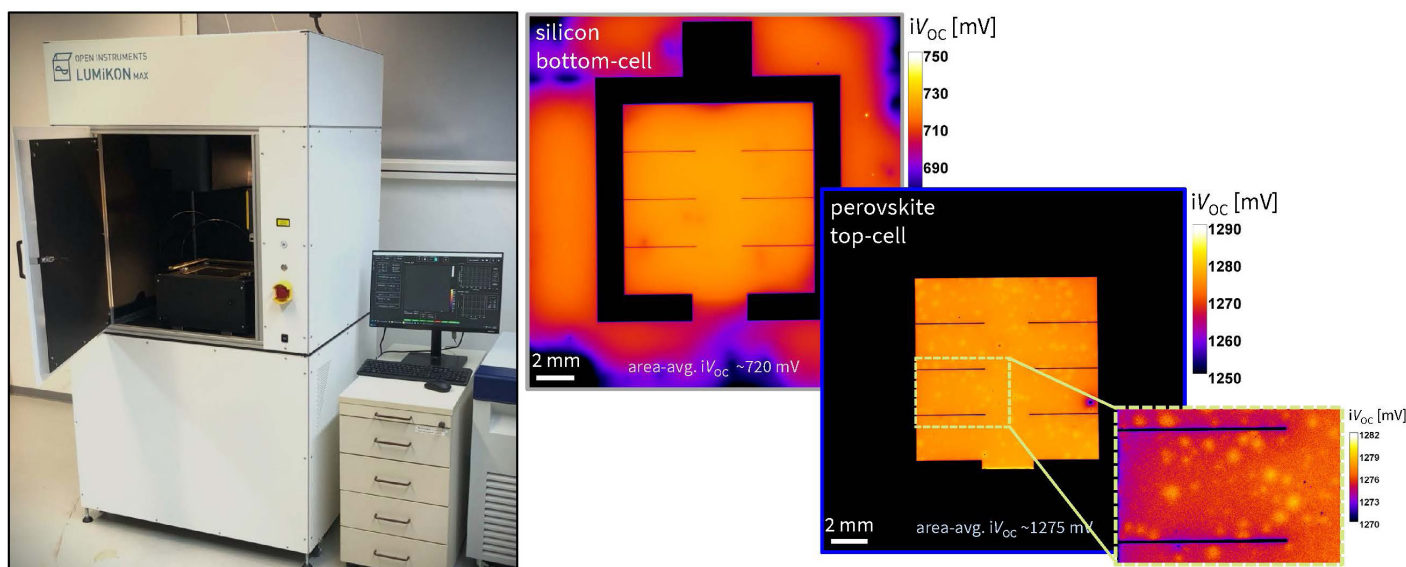
Q: What new possibilities does this equipment open up for your research on tandem solar cells?

We will be able to improve tandem scalability and long-term stability as well as module reliability striving for deeper understanding of the instability mechanisms behind.

Photoluminescence imaging tool

As tandem devices scale up, maintaining uniform opto-electronic properties becomes increasingly important. Photoluminescence imaging (PLi) offers a non-invasive way to map key parameters. Long used in silicon PV, this technique now delivers major benefits for perovskite and tandem cells. Recently, HZB integrated a unique, large-area PL imaging tool, LUMiKON MAX from Open Instruments, into its lab setup, enabling PEPPERONI researchers to analyse monolithic perovskite/silicon tandem solar cells with exceptional precision.

It allows for contactless measurement of absolute calibrated implied open-circuit voltage (iV_{OC}) and fill factor (iFF) for each photoactive layer of the tandem solar cell in a single, non-destructive measurement. Access to these parameters is essential for identification of the limiting factors and evaluating the energy conversion capabilities of sub-cells in a tandem device, enabling efficient fabrication process optimization. Advanced functionalities are included, like temperature-dependent measurements and the ability to measure luminescence spectrum at user-defined points or areas within an image.



what does it bring?

Q: How will the upgraded lab infrastructure contribute to PEPPERONI's overall goals?

Indoor testing and outdoor monitoring is key for understanding and improving perovskite and tandem performance under real operating conditions as we already learned in the past 4 ½ years we did this already. It is essential to bring this fascinating technology to the market.

Q: What are you most excited to explore using the new tools at HZB?

Our new PL imaging tool will boost development speed by fast access to device performance of large area tandems up to 210 x 210 mm².



Arman Mahboubi Soufiani (HZB)

PostDoc / Research Scientist, Perovskite-based Solar Cell Fabrication by Thermal Evaporation

We are very excited about its capability for absolute-calibrated parameter access of the individual sub-cells as well as the temperature- and spectral-dependent measurement options opening a deeper insight in the functionality of our tandem devices which we develop within PEPPERONI.

Swiss Center for Electronics and Microtechnology is a technology innovation centre developing advanced technologies with a high societal impact, that operates in the domains of precision manufacturing, digitalisation and sustainable energy. More specifically, through its activities, CSEM provides a full range of services to partners, ranging from technology development to product prototyping, including the realization of full-size demonstration systems.

Cleanroom and infrastructure

CSEM grouped its equipment for perovskite/silicon tandem solar cells processing in an ISO class seven (7) cleanroom to improve production throughput and process reproducibility. This clean room infrastructure includes the necessary equipment for sputtering, thermal evaporation, solution processing (spin, blade, slot-die coating, inkjet printing), screen printing or laser scribing.

CSEM's infrastructure includes speciality systems for thin-film coating, patterning, printing, fabrication processes, and pilot manufacturing lines – from wafer etching up to the assembly of fully functional PV modules and systems. In PEPPERONI, partners from CSEM lead work on [module integration of high efficiency tandems](#) and contribute to cell development and reliability testing activities.



what does it bring?

Q: What makes these new facilities unique or different from what was available before?

Our perovskite solar cell processing activities used to be spread across two buildings. This new facility groups all the necessary methods to produce high-efficiency perovskite/silicon tandem solar cells in the same laboratory, hence improving our production throughput. Also, being in a clean room environment is expected to improve the quality of our devices: this is particularly the case for solution-processed perovskite films manufactured outside of gloveboxes.

Q: How important is a controlled environment when working with perovskite/silicon tandem structures?

Numerous studies have shown that processing defects, e.g. due to the presence of dust, accelerate the degradation of perovskite solar cells during



Quentin Jeangros

Group leader of perovskite activities at CSEM
PEPPERONI WP4 lead

reliability testing. By processing our devices in a clean room environment, we aim to reduce the occurrence of such critical defects and hence improve the durability of our devices.

Watch the tour

PEPPERONI on the road

where did you see us so far?

From January until June, PEPPERONI partners presented at conferences and events, including ...



23 January - CINEA Clustering Event [Read more](#)



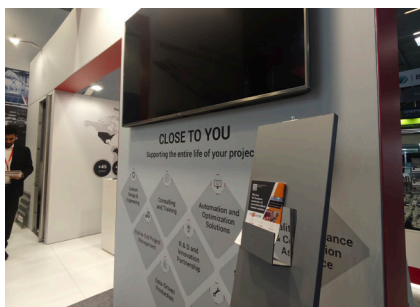
11-12 March - PV CellTech Europe [Read more](#)

SiliconPV npworkshop
15th International Conference on Crystalline Silicon Photovoltaics 2025 Oxford 2025

Confirmed Keynote Speaker
Bernd Stannowski



8-11 April - SiliconPV Conference [Read more](#)



6-7 May - Intersolar Europe [Read more](#)



13-15 May - Tandem PV Workshop [Read more](#)



20-22 May - FuturePV Workshop [Read more](#)

With the project progress, PEPPERONI partners are actively disseminating the research results at key PV conferences and events. Stay tuned to not miss out on the opportunities to gain insights into technology advancements, including encapsulation materials and strategies, tandem cells degradation processes and more.



what to expect?

International conferences and events

PEPPERONI partners continue to share their research results at key events and conferences, including PSCO 2025, EU PVSEC, MIW and more. Don't miss the opportunity to meet our partners!

PSCO 2025

From 15-18 September, the 8th rendition of the [PSCO Conference](#) will be held in Perugia, Italy. The topics for this conference are perovskite solar cells and optoelectronics. This international conference will be an opportunity to exchange knowledge between various fields of expertise and facilitate the development and commercialisation of European PV modules

EU PVSEC

From 22-26 September, [EU PVSEC 2025](#) will take place in Bilbao, Spain. It is the largest international Conference for Photovoltaic research, technologies, and applications and at the same time a PV Industry Exhibition, where specialized PV Industry presents technologies, innovations, and new concepts in the upstream PV sector.

Metallization & Interconnection Workshop

From 20-21 October, the 13th edition of the [MIW workshop](#) will be held in Berlin, Germany with tours to different labs of HZB as part of the **PEPPERONI industry workshop**. This includes Outdoor PV module test site and perovskite solar cells development lab. [Register today](#).

[See calendar](#)



Stay connected

what is in there for you?

Our newsletter not only brings you closer to PEPPERONI but also provides:

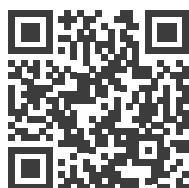
- Updates on the latest advancements and breakthroughs in perovskite/silicon tandem technology from PEPPERONI partners.
- Valuable insights, analysis, and expert opinions in PV value chain innovation.
- A community of like-minded individuals and experts, fostering collaboration and knowledge exchange.
- Potential opportunities for partnerships, investments, or career advancements in PV research/industry.

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The project is also supported by the Swiss State Secretariat for Education, Research and Innovation (SERI).

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takes you further

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