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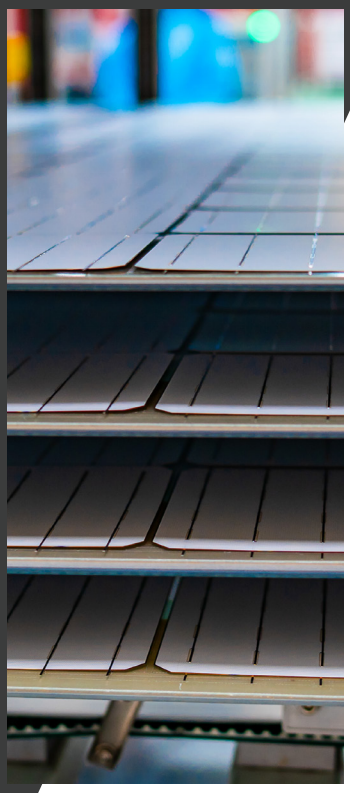
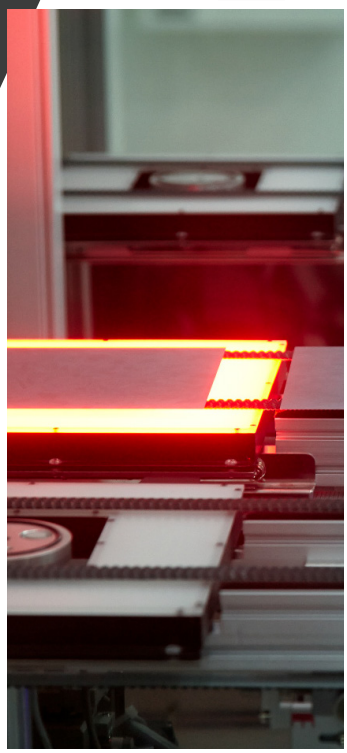
Shaping the future of solar energy with tandem technology

pepperoni-project.eu





Newsletter #2

Welcome to the second issue of the newsletter of the PEPPERONI project!
Embark on a journey through 2024 with us as we explore the multifaceted world of photovoltaics (PV) - from policy developments to industry trends and breakthroughs in research.

"The solar photovoltaic (PV) manufacturing sector is key for achieving our energy, climate, and competitiveness goals. We must ensure the solar industry remains strong for Europe's future, renewables-centred energy mix." - Kadri Simson, European Commissioner for Energy.

Inspiring words in the challenging times for European PV manufacturers.

Low global sales prices of solar panels, which have dropped to 7-9 €ct/Wp make it difficult to remain competitive, especially when the competition from China and the U.S. has intensified over the last years.
This has put pressure on European manufacturers and Chinese producers, several of whom are already facing insolvency due to ongoing consolidation in China. Despite these challenges, there is cautious optimism due to several strategies put in place by the European Commission (EC).

Co-funded by the European Union

Coordinated jointly by
HZB Helmholtz Zentrum Berlin
qcells

Developments

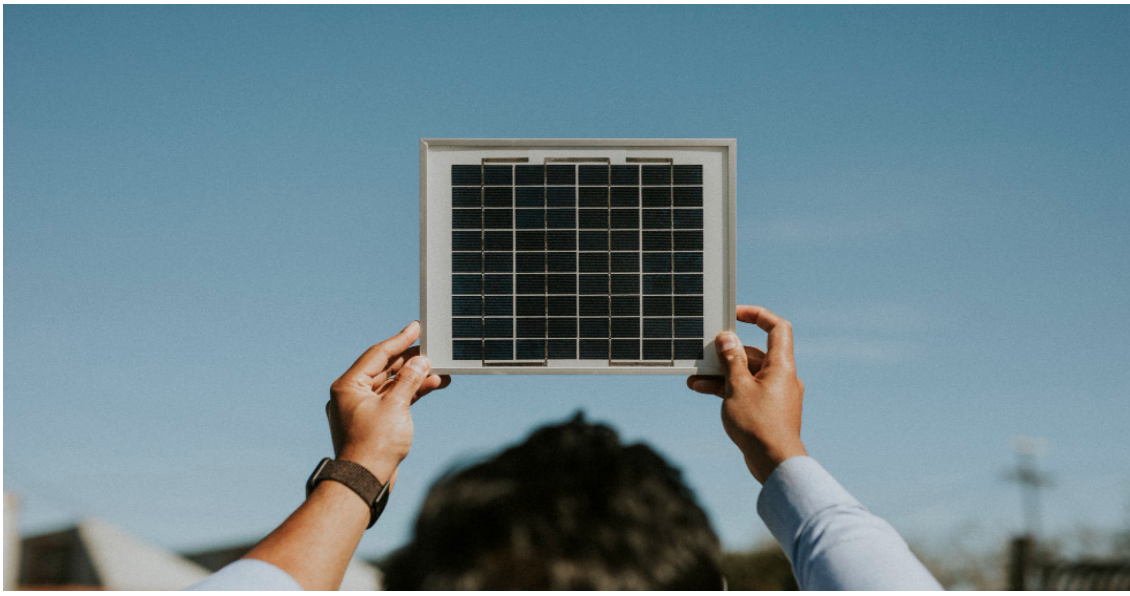
what are the EC strategies?

European Solar Charter
Introduced in April 2024, this charter outlines voluntary actions by the European Commission, EU Member States, and industry stakeholders. It advocates for accelerated permitting processes for solar projects and manufacturing facilities, ensuring faster deployment and reducing bureaucratic delays. It also aims to enhance access to EU funding and promotes advanced applications like agrivoltaics and building-integrated PV, fostering industry growth while aligning with Europe's energy transition goals. Read more

The Net-Zero Industry Act (NZIA)
The NZIA came into force on June 29 2024, setting a goal for the EU to produce 40% of its solar panels, wind turbines, heat pumps, and other clean technology solutions domestically by 2030. The NZIA aims to reduce dependency on imports and enhance the EU's competitiveness in the green technology sector.
As prices stabilise over the next 1.5 to 2 years, it is anticipated that European PV manufacturing could become competitive with Chinese suppliers, especially in terms of Levelized Cost of Energy (LCOE). Read more

Co-Programmed European Partnership
As part of the Horizon Europe Strategic Plan 2025-2027, the EC decided to form an official partnership for solar with the European Technology and Innovation Platform (ETIP-PV). Read more

what are PV trends in 2024?



The **International Technology Roadmap for Photovoltaics (ITRPV)** highlights the PV industry's shift towards monocrystalline silicon (mono-Si) modules, with new products dominated by M10 and G12 wafer formats and bifacial module technology. This transition has led to higher average module efficiencies, with new power classes reaching 700W and above. As prognoses show, improvements in all fields will result in module area efficiency increase: today's mainstream p-type mono-Si based PERC modules reach efficiencies of 21.4%, modules based on n-type cell technologies including TOPCon and SHJ technology provide highest power modules with today's efficiencies of more than 23% that will increase up to 24% within the next 10 years.

The **International Energy Agency (IEA) PVPS Trends Report 2024** notes that the global PV cumulative capacity grew to 1.6 TW in 2023, up from 1.2 TW in 2022, with 407.3 GW to 446 GW of new PV systems commissioned. This growth underscores the increasing adoption of advanced PV technologies and the advancements of emerging PV technologies, including perovskite/silicon (perovskite/Si) tandems.
Recent advancements of the technology have led to significant efficiency improvements, positioning it as a promising candidate for next-generation solar energy solutions.

Industry insights

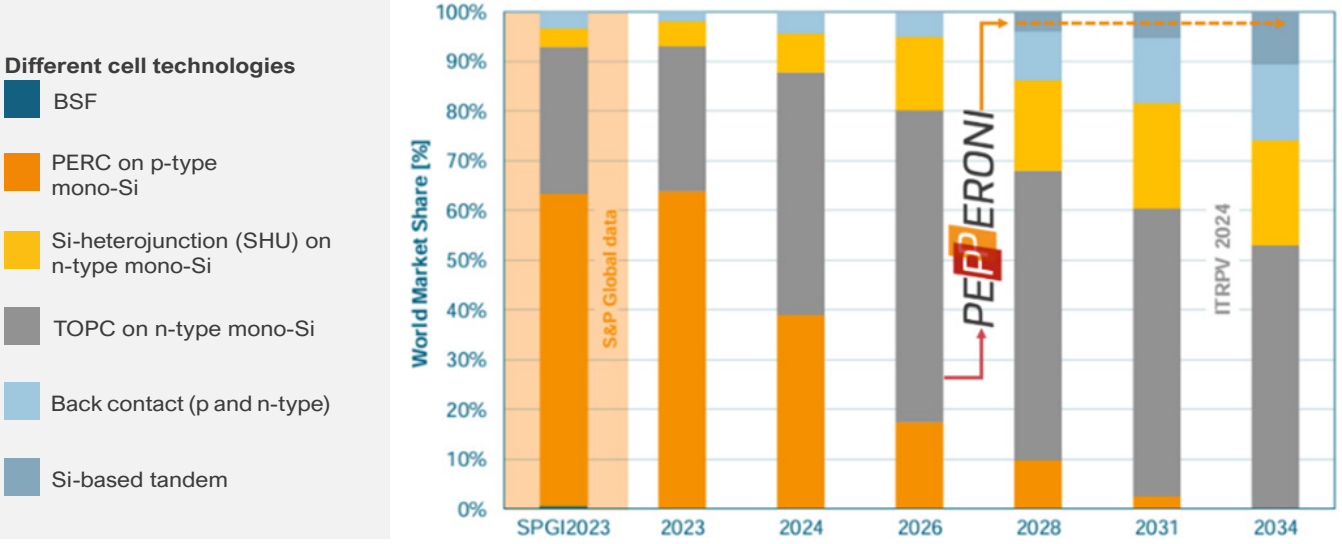
what is the market interest?

In June 2024, LONGi Green Energy Technology Co., Ltd. announced a major breakthrough in the development of its perovksite/Si tandem solar cells, achieving a power conversion efficiency of 34.6%, as certified by the European Solar Test Installation (ESTI). Read more

Meanwhile, Oxford PV has introduced a first tandem module prototype with record efficiency marking 26.9% (modules by OxPV available commercially reach 24.5% - total area). Read more

Qcells has been also actively investing in perovskite tandem technology. Following a series of R&D feats in developing highly efficient small-area tandem solar cells, Qcells has pivoted its focus to large-area tandem development, which lead **to a new world record with a 28.6% efficiency** for tandem solar cells. The value is a total-area measurement on a full-area M10-sized cell that can be scaled for mass manufacturing. This milestone, independently verified by the CalLab at the Fraunhofer Institute for Solar Energy Systems (ISE), demonstrates Qcells' advances in scalable, commercial processes that bring the industry closer to commercialising tandem solar technology. Read more.

These developments indicate a trend towards the market introduction of perovskite/Si tandem PV modules. As reported by ITRPV, Si-based tandem cells and modules might enter mass production around 2027, starting with module efficiencies of about 27%. Perovskite/Si tandem PV technology holds thus significant promise due to its high efficiency potential, but some challenges remain that must be addressed before large-scale commercialisation is feasible.



Ref: ITRPV, 2024. *"Market shares for different cell technologies."* https://www.vdma.org/international-technology-roadmap-photovoltaic

what are the key challenges?

The challenges include technical ones, such as ensuring long-term stability and mitigating performance degradation caused by environmental factors like moisture, oxygen, and heat. Achieving efficient integration of perovskite layers with silicon substrates without defects, as well as developing durable encapsulation methods, is critical.
Additionally, translating high laboratory efficiencies to larger-scale modules remains challenging, alongside addressing toxicity concerns related to lead in many perovskite formulations. Upscaling challenges include optimising manufacturing processes for high throughput and low cost while ensuring material supply chain reliability.

Significant capital investment is needed to build or retrofit production lines for tandem technology, and standardising performance and durability testing is essential for market adoption.
Overcoming these barriers requires collaboration between research institutions and industry players.

Project insights

what is the goal?

In our video, the project coordinator, Bernd Stannowski from Helmholtz Zentrum Berlin, elaborates on the shift towards perovskite and key challenges. PEPPERONI aims to address different barriers to performance, manufacturing and socio-economic aspects to facilitate the industrial deployment of perovskite/Si tandem solar modules.

challenges - what and how?

Material supply: A reliable supply of high-purity materials for perovskite fabrication at industrial scale poses logistical and cost challenges. PEPPERONI is committed to removing environmental hotspots by employing eco-design approaches from the start of the development process. This includes reducing the need for scarce materials and ensuring the sustainability of the supply chain through trusted partnerships.

Toxicity concerns: All high-performing perovskite formulations use lead, raising environmental and regulatory concerns. While developing lead-free or lead-reduced alternatives remains an ongoing area of research, these alternatives are far from reaching the technical maturity and stability of current lead-based perovskites. PEPPERONI includes a comprehensive life cycle assessment (LCA) to evaluate the actual environmental and health impacts of materials and processes used throughout the product's life cycle, from raw material extraction to end-of-life disposal. We report on the first results in the article featured below in this newsletter.

Stability and degradation: Perovskite materials degrade due to moisture, oxygen, heat, and UV exposure. PEPPERONI aims to extend the operational life of perovskite/Si tandem cells to over 30 years. Project partners conduct rigorous testing under controlled conditions to simulate real-world stressors. Indoor accelerated ageing identifies failure mechanisms and predicts longevity, while outdoor monitoring collects performance data across diverse climates. These insights guide material and encapsulation improvements for durable and reliable PV modules.

Durability: Achieving durable perovskite/Si tandem cells requires both intrinsically stable cell stacks (resistant to light and temperature) and robust encapsulation (protecting against moisture and oxygen) without adding cost or reducing efficiency. In PEPPERONI, partners optimise deposition processes for perovskite absorbers, ensuring stability and scalability. They refine deposition methods, buffer layers, and contact materials to enhance performance and industrial compatibility while developing advanced encapsulation techniques to protect cells and maintain efficiency.

Efficiency scalability: Lab-scale perovskite/Si tandem cells have surpassed 34% efficiency, but scaling this to larger modules is challenging due to manufacturing inconsistencies. PEPPERONI addresses this by optimising materials and processes to boost power conversion efficiency (PCE) while minimising cell-to-module losses during interconnection and encapsulation.

Manufacturing: Current lab-based methods require optimisation for high-throughput, low-cost mass production. To enable tandem technology adoption, adapting existing silicon cell production lines must be economically feasible. PEPPERONI advances deposition processes and equipment for scalable, efficient manufacturing while minimising scaling losses. This work supports establishing a fully integrated tandem cell and module pilot line.

Standardisation: No specific standards currently exist for perovskite/Si tandem solar cells, with silicon PV standards often used as a reference despite their limitations. PEPPERONI leverages European expertise from research to industrial manufacturing to facilitate the development of industry standards for testing and certifying tandem cells' performance and durability, which is essential for market acceptance.

Technology advances

what is our TRL?

Technology Readiness Level (TRL) is a systematic metric used to assess the maturity of a particular technology. PEPPERONI aims to advance the technology's readiness from an average TRL of 4–5 ("validated in the lab/relevant environment") to TRL7 ("a system prototype demonstrated in an operational environment").
As we read in the Qcells' recent announcement, the perovskite/Si tandem solar cell technology has already reached at least TRL6 indicating that a prototype system has been demonstrated in a relevant environment. This milestone with a certified efficiency of 28.6% on a full-area M10-sized cell, bridges the gap between laboratory research and industrial-scale production and underscores significant progress toward commercial viability.

Read more

what is the technical progress?

Samples and expertise from technology development work packages are used to test tandem solar cell stability and evaluate their environmental and societal impacts. In 2024, PEPPERONI partners produced 12 technical deliverables, including 11 on **the technology development**:

- **WP2:** Setup of infrastructure for pilot line
- **WP3:** Evaporated perovskite for tandem perovskite/Si solar cells, Wet- or hybrid-processed perovskite, New materials and the role of perovskite precursor purity on cell performance, Use of atomic layer deposition for mass production of tandem solar cells
- **WP4:** Single-cell and 4-cell mini-module with little cell-to-module (CTM) loss
- **WP5:** Specifications for the upgrade of the interconnection tool
- **WP6:** Electrode transport layers (ETL) materials, Production methods of perovskite precursors, Production methods of self-assembled hole and electrode transport layers (HTL, ETL)

and one on **the technology assessment:**

- **WP8:** Report on eco-design

Fabian Fertig (Qcells)
technology development
coordinator

"Qcells is excited to announce this new world-record in tandem cell efficiency. The champion cell is a typical cell from our R&D pilot line in Germany and has been fabricated by exclusively using processes that are feasible for mass production..."

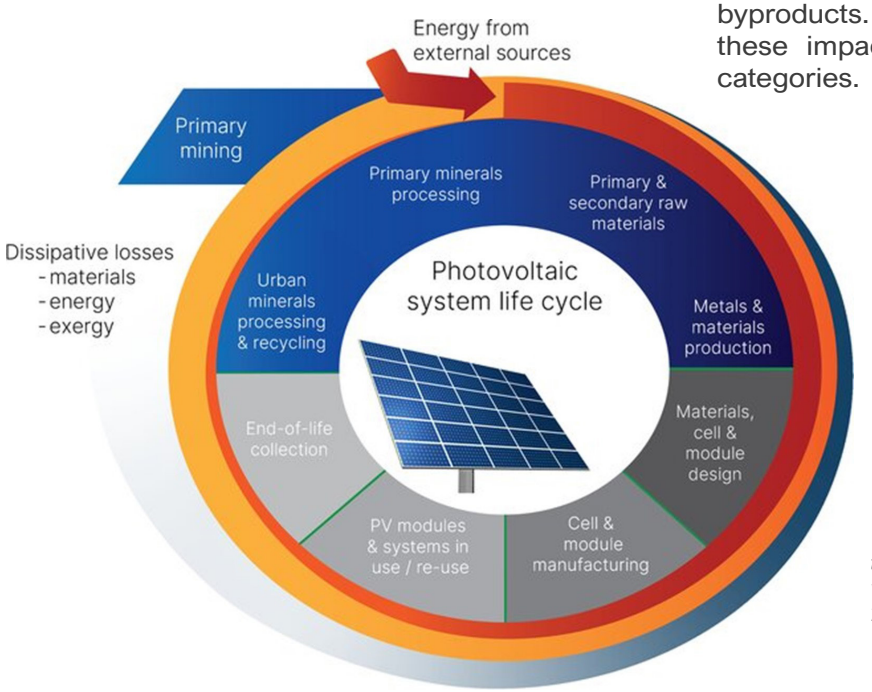
Read more

Hear from PEPPERONI

what is LCA?

LCA (Life Cycle Assessment) is a standardised methodology for evaluating the environmental impacts of a product throughout its entire life cycle. By assessing each stage, from resource extraction and manufacturing to usage and disposal, LCA identifies opportunities for improving sustainability. It enables data-driven decisions to mitigate negative environmental impacts.

While reducing carbon dioxide (CO2) emissions is a major focus of clean energy solutions, comprehensive LCA extends beyond this metric, considering factors such as energy consumption, resource use, waste generation, and pollution. For PV technologies, production processes often involve mining rare materials, energy-intensive manufacturing, and generating hazardous byproducts. LCA provides a holistic view of these impacts, covering multiple environmental categories.



Ref: Bartie et al.,*"Metallurgical infrastructure and technology criticality: the link between photovoltaics, sustainability, and the* metals industry", 2022

how do we do it in PEPPERONI?

In PEPPERONI, LCA is integrated into early-stage decision-making to enhance sustainability in the development of emerging PV technologies. To this end, our LCA adheres to IEA Task 12 guidelines and includes four phases: goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA), and results interpretation.

Assessment done in PEPPERONI thus evaluates the environmental impacts of manufacturing 1m² of perovskite/Si tandem modules, with system boundaries set from raw material extraction to production (cradle-to-gate). We analysed four perovskite stacks based on different materials and deposition methods. Collaboration between academic, research and industrial partners enhanced the accuracy of collected data. As we learned, **key differences** in environmental impact arise from the absorber layer (slot-die coating vs. co-evaporation) and the electron transport layer (sputtered NiOx vs. evaporated 2PACz). In our work on LCA, we used the Environmental Footprint 3.1 method for its role in fostering transparency, comparability, and reliability.

As results reveal, electricity consumption during manufacturing drives most impacts, with material usage playing a secondary role. Evaporation deposition stands out as a critical hotspot due to its high energy demand. Overall, perovskite cells have minimal environmental impacts compared to silicon cell production and module assembly. For silicon cells, electricity and silver in metallization paste are key contributors, while materials like solar glass, aluminum alloys, and EVA dominate module assembly impacts. It is worth noting, that production in Europe has lower impacts than in China, due to cleaner energy sources.

Moving forward, the project will adopt a cradle-to-grave perspective, analysing the entire lifecycle of PV modules, including the use and End-of-Life (EoL) phases. The functional unit will shift from 1m² of PV panel to 1 kWh of electricity, incorporating parameters like efficiency, lifespan, and performance. This expanded analysis will also explore opportunities for reducing, recycling, and reusing materials, aligning with the project's sustainability goals.

PEPPERONI on the road

where did you see us in 2024?

PEPPERONI partners presented at key PV conferences and events, including

5-9 May - SETAC Europe 34th Annual Meeting
Read more

19-21 June - Intersolar Europe 2024 Read more

26-28 June - TandemPV workshop Read more

23-27 September - EU PVSEC 2024 Read more

22-23 October - Enlit Europe Read more

20-22 November - BECOME PV 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.

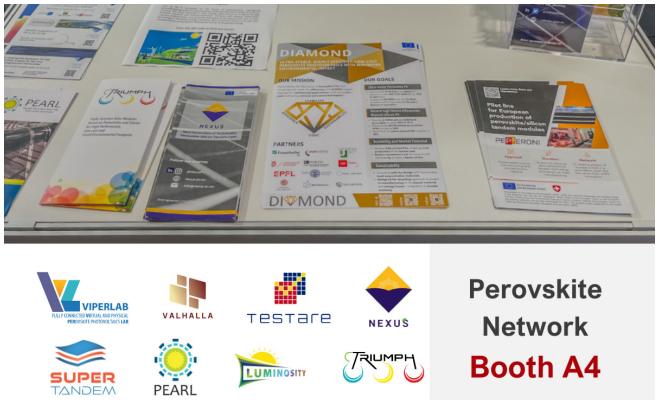
Subscribe

News & collaborations

what did you miss?

How can cross-project collaboration drive innovation? By sharing knowledge, aligning efforts, and leveraging diverse expertise to accelerate advancements and address challenges.
At the EU PVSEC conference, PEPPERONI held a joint booth with other EU-funded projects focused on perovskite technologies.

Conference attendees showed a high interest in the network.
To meet the expectations, we launched a new webpage providing an easy overview of EU-funded project advancing perovskite technologies.
See projects.



In 2024, the PEPPERONI consortium met twice to discuss the project progress and define next steps:

- The 4th General Assembly (GA) hosted by Laboratory of Photovoltaics and Optoelectronics at the University of Ljubljana (LVPO), on 23-24 May in Ljubljana, Slovenia.
- The consortium members took a new approach to the meeting format with the 5th GA hosted by the Polymer Competence Center Leoben GmbH (PCCL) in Leoben, Austria on 21-22 October.

More news

what to expect?

CINEA clustering event

On January 23rd, the PEPPERONI coordinators from HZB and Qcells, will join the clustering event in Brussels, Belgium organised by the Horizon Europe Energy Unit at European Climate, Infrastructure and Environment Executive Agency (CINEA). The event will focus on the comercialisation patways of advanced solar cells and modules, bringing together experts from diverse fields and projects.

Interesting PV call topics

The draft work programme for Horizon Europe's Climate, energy and mobility for 2025 includes a few interesting PV topics (ETIP-PV Partnership).
Potential deadlines in September 2025 and February 2026. Stay tuned to our LinkedIn to hear more!

PEPPERONI webinar

In late February 2025, PEPPERONI will host a webinar focused on perovskite-based technologies with the idea of showcasing innovative research and various perovskite technologies at different technology readiness levels.
We are working on the programme, so look out for any updates!

International conferences and events

PEPPERONI partners continue to share the research results at key events and conferences, including Intersolar Europe 2025, EU PVSEC, PSCO, Tandem PV Workshop and more.
Don't miss the oportunity to meet our partners!

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.

Subscribe today to embark on an exciting journey of research and innovation!

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acknowledgement

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