SAFE 2025

International Workshop on

Solar Applications For Environment

Ecodesign and sustainability of materials, systems, technologies and processes in the energy transition

Abstract Book

Aula Capitò - Dipartimento di Ingegneria
Università di Palermo
Viale delle Scienze – Palermo

3-5 December 2025

Funder: Project funded under the National Recovery and Resilience Plan (NRRP), Mission 4 Component 2 Investment 1.3 - Call for tender No. 1561 of 11.10.2022 of Ministero dell'Università e della Ricerca (MUR); funded by the European Union – NextGenerationEU
Award Number: Project code PE0000021, Concession Decree No. 1561 of 11.10.2022 adopted by Ministero dell'Università e della Ricerca (MUR), CUP - to be indicated by each Beneficiary, according to attachment E of Decree No. 1561/2022, Project title "Network 4 Energy Sustainable Transition – NEST"

NEST
NETWORK FOR ENERGY SUSTAINABLE TRANSITION

Finanziato dall'Unione europea
NextGenerationEU

Piano Nazionale di Ripresa e Resilienza (PNRR)
Missione 4 – Componente 2 – Investimento 1.3
Avviso N.341 -15.03.2022 MUR

Titolo del progetto
Network 4 Energy Sustainable Transition
NEST - SPOKE 1

Codice progetto
PE0000021
Decr. N.1561 – 11.10.2022
CUP B73C22001280006

Soggetto Attuatore
Università degli Studi di Palermo
Piazza Marina 61
90133 - Palermo

Obiettivo principale dell'operazione
"Scenari energetici del futuro"

Spoke 1 aims at boosting the Photovoltaics (PV) and Concentrated Solar Power/Concentrated Solar Thermal (CSP/CST) sectors toward higher amount of renewable energy production at competitive costs, overtaking actual limits and introducing innovative research at low Technology Readiness Level (TRL).

Workshop Organizer:

Spoke 1 NEST NETWORK FOR ENERGY SUSTAINABLE TRANSITION

Workshop Co-Organizers:

Spoke 9 NEST NETWORK FOR ENERGY SUSTAINABLE TRANSITION

ASSOCIAZIONE RETE ITALIANA LCA

Centro di Sostenibilità e Transizione Ecologica

Finanziato dall'Unione europea NextGenerationEU | Ministero dell'Università e della Ricerca | Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA | NEST NETWORK FOR ENERGY SUSTAINABLE TRANSITION

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Program

Day 1 – Wednesday 03 December 2025

Morning

9:00	10:00	**WELCOME SESSION** Chair: Maurizio Cellura Prof. **M. Midiri** - Rector UniPa Prof. **A. Pace** - Delegate UniPa Prof. **L. Fratini -** UniPa Head of Engineering Department Dott. **L. Tropea -** UniPa Head of Research and Innovation Prof. **G. Palma** – UniPa Head of Physics and Chemistry Department Avv. **G. Savarino** - Assessore territorio e ambiente Reg. Siciliana Dott. **V. Infantino -** General Manager ARPA Sicilia Dott. **C. Frittitta** - General Manager - Dipartimento dell'Energia Reg. Siciliana Ing. **G. Graditi** - General Manager ENEA Dott. **W. Sparber** - Head of the Institute for Renewable Energy- Eurac Research Prof. **F. Pilo** - Vicepresident Fondazione NEST
Session I:		**General Meeting** Chair: **Mario Tucci** **Simona Barison**
10:00	10:20	**Rosario Miceli**, MOST Project *National Sustainable Mobility Center*
10:20	10:40	**Rosalinda Inguanta**, SAMOTHRACE Project *Environmental Assessment of NiFeP Nanowire Electrodes*
10:40	11:00	**Paolo Corti**, MC2.0 Project *Processes, Stakeholders, Industry and Market Needs for PV Mass Customization*
11:00	11:30	Coffee break
11:30	11:50	**Isodiana Crupi**, University of Palermo *Innovative Thin-Film Solar Cell Solutions For a Sustainable Energy Transition*
11:50	12:10	**Giulia Monteleone**, ENEA *The Role of Research and Innovation for a Strong National and European Ecosystem of Hydrogen*
12:10	12:30	**Roberto Sannasardo**, Energy Manager Regione Sicilia *Energy Scenarios of the Sicilian Region*
12:30	12:50	**Massimo Mazzer**, Rete Italiana Fotovoltaico *ReteIFV: Vision and Strategies of the Italian Photovoltaic R&I Community*
12:50	14:30	Lunch

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NEST NETWORK FOR ENERGY SUSTAINABLE TRANSITION

Program

Day 1 – Wednesday 03 December 2025

Afternoon

Session II:		**GDL Energia e Tecnologie Sostenibili - Rete Italiana LCA**	Chair:	**Sonia Longo** **Maria Laura Parisi**
14:30	14:40	**Monica Lavagna**, Politecnico di Milano *Greetings from the Head of LCA*		
14:40	14:55	**Mercy Jelagat Kipyator**, University of Siena *Prospective Life Cycle Assessment for the Eco-Design of Perovskite/Silicon Tandem Solar Cells from the Lab Scale to Industrial Solar Devices*		
14:55	15:10	**Roberta Rincione**, University of Siena *Assessing the Spillover, Multiplier and Feedback Effects of Low Carbon Energy Technologies in Italy*		
15:10	15:25	**Teresa Maria Gulotta**, University of Messina *Early Design Evaluation Through Life Cycle Assessment and Environmental Life Cycle Costing: Lessons from the Nanoscale Energy Harvester Case*		
15:25	15:40	**Massimiliano Mariani**, CNR STIIMA *How Technology and Installation Shape the Environmental Sustainability of Photovoltaic Modules*		
15:40	15:55	**Marina Mistretta**, University of Reggio Calabria *The Assessment of the Life-Cycle Economic and Social Impacts of HGRSS: The experience of the FUD-OF-SITHY Project*		
15:55	16:10	**Maurizio Cellura**, University of Palermo *Environmental Impacts of HGRSS: The Experience of The FUD-OF-SITHY Project*		
16:10	16:40	Coffee Break		
Session III:		**Innovative Technologies and Sustainability for Photovoltaics**	Chair:	**Marco Cannas**
16:40	17:00	**Emanuele Marino**, University of Palermo *Emergent Properties from Nanocrystal Superstructures*		
17:00	17:20	**Yuliya Katsyuk**, FuturaSun s.r.l. *Sustainability in Photovoltaics*		
17:20	17:40	**Marina Foti**, 3Sun *Gigawatt-Scale Solar in Europe: Overcoming Challenges and Driving HJT & Tandem Innovation*		
17:40	18:00	**Giuseppe Arrabito**, University of Palermo *Environmental Impacts of Perovskite Solar Cells: An Analytical Approach*		

Program

Day 2 – Thursday 04 December 2025

Morning

9:00	10:00	**WELCOME SESSION** Chair: Maurizio Cellura Dott. **G. Scapicchio** - General Manager Fondazione NEST Dott. **M. Chimienti** - Research Manager Fondazione NEST Prof. **G. Parisi** - UniPa Coordinator of Biodiversity Gateway Activities Dott. **G. Cecchini** - Ordine Geologi Sicilia Prof. Ing. **V. Di Dio** - Ordine Ingegneri Palermo Dott- **D. Monti** - Ordine Agronomi Palermo Dott.ssa **F. Salemi** - Ordine Commercialisti Palermo Dott. **L. Spicola** - Ordine Medici Palermo Prof.ssa **S. Rainieri** - Associazione Fisica Tecnica Italiana		
Session IV:		**Spoke 1**	Chair:	**Maurizio Cellura** **Michela Chimienti**
10:00	10:20	**Giulia Spaggiari**, Italian Institute of Technology *Enhancing the Performance of Sb_2Se_3 Thin-Film Solar Cells: Strategies for Optimization and the Role of Advanced Characterization*		
10:20	10:40	**Wolfram Palitzsch**, LuxChemtech *Recycling Along the PV Production Chain, Including Results from Photorama and Icarus EU Projects*		
10:40	11:00	**Ofelia Durante**, University of Salerno *Photoconductivity and Stability of 2D Perovskites: Exploring Lead and Tin-Based Materials for Future Optoelectronic and Neuromorphic Applications*		
11:00	11:20	**Pedro Horta**, University of Évora *Molten Salt Storage as an Energy Hub for the Energy Transition*		
11:20	11:50	Coffee Break		
Session V:		**Spoke 9**	Chair:	**Gabriella Scapicchio** **Simona Barison**
11:50	12:10	**Serena Berardi**, University of Ferrara *Photoanodic Interfaces for Applications Relevant to Solar Fuels Production*		
12:10	12:30	**Andrea Brigliadori**, CNR ISSMC *Tailoring Metal Exsolution in Doped Oxides*		
12:30	12:50	**Francesco Paolucci**, University of Bologna *Carbon-Based Hierarchical Nanostructures for Electrocatalysis*		
12:50	13:10	**Andrea Dini**, CNR IGG *From Earth to Energy Transition: Geothermal Systems, Critical Raw Materials and Mineral Carbonation*		
13:10	14:30	Lunch		

Program

Day 2 – Thursday 04 December 2025

Afternoon

Session VI:		**Bandi a Cascata (BAC) Spoke 6, 7, 8** — Chair: **Francesco Guarino**
14:30	14:50	**Elisa Moretti**, BAC Nanoplus *Nanostructured Photo/Electro Composites for the Production of H_2 and High Added-Value Chemicals by Water Splitting and CO_2 Reduction (Nano-Plus)*
14:50	15:10	**Gianpiero Evola - Antonio Barbera**, BAC Life Agro *Tracking System with Thin-Film PV Technology for Resilient Agriculture: The Results of Life Agro-PV*
15:10	15:30	**Claudio Cignali**, BAC Re.S.T.O.Re. P.V.P *Sustainable Demanufacturing of Crystalline Silicon Photovoltaic Panels Through Cryogenic Delamination and Selective Leaching*
15:30	15:50	**Martina Capone**, CNR IMM *Exploring the Potential of Urban Aquifers for Seasonal Thermal Storage*
15:50	16:10	**Antonio Di Tommaso - Andrea Culcasi - Costanza Tedesco**, University of Palermo *The Acid/Base Flow Battery: An Innovative Salinity and pH Gradients Storage Device*
16:10	16:40	Coffee Break
16:40	17:00	**Eleonora Riva Sanseverino**, University of Palermo *Smart Sector Integration and Sustainability*
17:00	17:20	**Gianluca Scaccianoce - Francesco Montana**, University of Palermo *Environmental Sustainability and Energy Efficiency in Buildings: The Nest Experience*
17:20	18:40	**Poster Session**
20:30		Social Dinner

Program

Day 3 – Friday 05 December 2025

Morning

NEST Session		Internal Meeting Spoke 1	Internal Meeting Spoke 9
9:00	9:30	Introduction by Spoke leader: **Maurizio Cellura**	Introduction by Spoke leader: **Simona Barison**
9:30	11:00	Internal Session: **Part 1**	Internal Session: **Parti 1**
11:00	11:30	Coffee Break	
11:30	13:00	Internal Session: **Part 2**	Internal Session: **Part 2**
13:00	13:30	Final Remarks	Final Remarks
13:30		Lunch	

ABSTRACTS

SESSION I

GENERAL MEETING

CHAIR Mario Tucci

CHAIR Simona Barison

NATIONAL SUSTAINABLE MOBILITY CENTER

Rosario Miceli[1]

1 Department of Engineering – University of Palermo, Italy, Viale delle Scienze, 90128 Palermo

The MOST project – National Sustainable Mobility Center – brings together 24 universities, the CNR, and 24 large companies to support the development of modern, sustainable, and inclusive mobility solutions across Italy. Its areas of work include air mobility, light vehicles and active mobility, waterway and rail transport, and new fuels. Sustainability is a core principle guiding technological development, assessment methods, and pilot projects.

UNIPA contributed to Spokes 2, 3, 9, and 12, and also participated in closed calls with projects linked to Spokes 4, 5, 11, and 13. Spoke 2 focuses on "zero-emission sustainable transport solutions" treating sustainability as both a research driver and a measurable performance factor. It develops methods to assess environmental sustainability—pollutant and noise emissions, congestion, CO_2 impacts, and life-cycle analyses—supporting data-driven evaluations and optimized planning.

Spoke 3 integrates circular economy principles, studying the reuse and recycling of battery materials and the modelling of circular processes. Research covers chemistry, materials science, and process optimization, aiming to reduce waste, maximize material recovery, and evaluate the sustainability of battery-recycling chains using advanced models and improved experimental workflows.

Spoke 9 addresses electric-charging infrastructure and energy management for mobility, emphasizing the sustainability of power electronics and grid solutions. Activities include developing innovative, grid-integrated charging technologies that reduce energy losses, facilitate renewable-energy integration, and improve the sustainability of electrified transport systems.

Finally, Spoke 12 enhances sustainability through predictive models, simulations, and digital twins for sustainable mobility and smart-city strategies. It develops computational tools to optimize transport flows, reduce inefficiencies, and assess sustainability scenarios for urban and regional mobility.

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ENVIRONMENTAL ASSESSMENT OF NiFeP NANOWIRE ELECTRODES

R. Inguanta[1], R. L. Oliveri[1], A. Affranchi[2], S. Longo[1], M. Cellura[1,2]

1 Department of Engineering – University of Palermo, Italy, Viale delle Scienze, 90128 Palermo
2 Center of Sustainability and Ecological Transition – University of Palermo, Italy, Piazza Marina 61, 90133 Palermo

The energy sector is one of the major contributors to greenhouse gas emissions, making it a crucial focus in the pursuit of decarbonization [1]. It is projected that by 2050, two-thirds of the energy sector will be powered by renewables [2]. In this context, hydrogen is expected to play a crucial role as an energy carrier, especially in managing the intermittency of renewable energy sources by storing surplus energy and releasing it when needed [3].
Alkaline electrolysers, while less efficient than Proton Exchange Membrane (PEM) electrolysers, are currently the most commercially mature technology for hydrogen production due to their lower costs, longer lifespan, and higher safety [4]. To improve the efficiency of alkaline cells, recent research has focused on the development of electrodes using nanostructured materials [5].
This study aims to evaluate the life cycle energy and environmental impacts of experimental nanowire electrodes made from a nickel-iron-phosphorus (NiFeP) alloy, investigating the effect of varying sodium hypophosphite (phosphorous precursor) concentrations on their performance considering three scenarios. The study follows the international standards of Life Cycle Assessment (LCA) methodology, utilizing an attributional approach.
Environmental impact results showed negligible differences between the three scenarios, with variations of less than 0.4%. A contribution analysis of the electrodes revealed that trichloromethane etching had the highest impact across four environmental impact categories, sputtering dominated in two categories, and similarly electrodeposition was the main contributor for two. Nickel sulfate and nickel chloride emerged as the main hot spots, whereas gold dominated the sputtering process, contributing over 90% of the environmental impact
In conclusion, this LCA study demonstrated that the environmental impacts of NiFeP nanowire electrodes are minimally affected by variations in sodium hypophosphite concentration. The results allowed to identify the main environmental hot spots in the production process. The results provide insights for future electrode design, highlighting opportunities for eco-design strategies that could reduce the environmental impacts of hydrogen production technologies.

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[2] International Energy Agency (IEA), "Net Zero by 2050 - A Roadmap for the Global Energy Sector," 2021, [Online]. Available: www.iea.org/reports/net-zero-by-2050
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[4] B. Yang, R. Zhang, Z. Shao, and C. Zhang, "The economic analysis for hydrogen production cost towards electrolyzer technologies: Current and future competitiveness," Int. J. Hydrog. Energy, vol. 48, no. 37, pp. 13767–13779, Apr. 2023, doi: 10.1016/j.ijhydene.2022.12.204.
[5] B. Buccheri, F. Ganci, B. Patella, G. Aiello, P. Mandin, and R. Inguanta, "Ni-Fe alloy nanostructured electrodes for water splitting in alkaline electrolyser," Electrochimica Acta, vol. 388, p. 138588, Aug. 2021, doi: 10.1016/j.electacta.2021.138588.

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PROCESSES, STAKEHOLDERS, INDUSTRY AND MARKET NEEDS FOR PV MASS CUSTOMIZATION

P. Corti[1], P. Bonomo[1], F. Frontini[1]

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Legislative frameworks like the Renovation Wave Strategy and the EU Solar Strategy highlight Europe’s commitment to accelerating the deployment of solar energy in the built environment. The Green Deal Industrial Plan and the Net Zero Industry Act (NZIA), adopted by the European Commission, aims to enhance the competitiveness of Europe's net-zero industry to reinforce the solar sector in Europe and facilitate the transition to climate neutrality. Together, these initiatives aim to increase renovation rates, promote photovoltaics as an integral part of building designs, support industrial-scale manufacturing of solar technologies, and increase the European production capacity for clean technologies, emphasizing the use of renewable energy, energy efficiency, and sustainable design.

Despite globalization, the construction sector remains dominated by local firms and practices, making it challenging for international companies to penetrate at a granular level. For Europe’s construction industry, the situation offers the potential to enhance the sector’s competitiveness while aligning with Europe’s climate and renovation goals. It also favours customization and flexibility over standard and mass-market options, as well as for stakeholders and the value chain looking for innovation and new products.

The presented research, supported by the European project Mass Customization 2.0 (grant agreement n° 101096139), aims to provide actionable insights and guidance for stakeholders across the integrated photovoltaic industry, from architects and engineers to policymakers and end-users, offering an overview of the BIPV market, mapping the roles of key players, highlighting the interdisciplinary collaboration needed to integrate photovoltaics into existing construction workflow and providing an overview of the industry across European regions. Through real-world data and case studies, the research supports the effective integration of photovoltaics into Europe’s construction sector, fostering innovation and ensuring Europe remains at the forefront of the global green transition.

INNOVATIVE THIN-FILM SOLAR CELL SOLUTIONS FOR A SUSTAINABLE ENERGY TRANSITION

I. Crupi[1], S. Morawiec[2], M.J. Mendes[3], D. Scirè[1], R. Macaluso[1], M. Mosca[1], M.P. Casaletto[4], O. Isabella[5]

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2 Faculty of Physics, Astronomy and Informatics – Nicolaus Copernicus University, Poland, Torun
3 Department of Materials Science – Universidade NOVA de Lisboa, Portugal, Caparica, 2829-516 Caparica
4 Institute of Nanostructured Materials (ISMN) – National Research Council (CNR), Italy, 90146 Palermo
5 Photovoltaic Materials and Devices Group – Delft University of Technology, Netherlands, Delft 2628CD

The transition toward a sustainable energy future requires solar technologies that combine high efficiency, material sustainability, and cost-effectiveness. Thin-film solar cells represent a promising alternative to conventional silicon-based devices, though their performance remains limited by optical and electronic losses. This contribution presents two research studies aimed at improving light management and charge selectivity in next-generation photovoltaic technologies.
The first study focuses on plasmonic nanostructures based on silver (Ag) nanoparticles (NPs) for enhanced light trapping [1-5]. Using a simple and scalable solid-state dewetting process, the morphology and distribution of Ag NPs were optimized to maximize optical enhancement. A novel spectroscopic method was developed to quantify both absorption gains and parasitic losses, showing that Ag NPs can deliver up to 90% useful absorption enhancement with negligible optical losses in the relevant wavelength range. The optimized plasmon-enhanced solar cells exhibit broadband external quantum efficiency improvement and a significant increase in short-circuit current density compared to reference devices. The second study provides a comprehensive analysis of molybdenum oxide (MoOx) and tungsten oxide (WOx) thin films as passivating hole-selective contacts for heterojunction (HJT) solar cells [6,7]. These transition metal oxides represent promising candidates for doping-free architectures, though their application is hindered by S-shaped J–V curves that limit device performance. To address this, the role of oxygen vacancies and defect density, evaluated through non-destructive photothermal deflection spectroscopy, was investigated. Solar cell prototypes incorporating MoOx and Wox contacts were fabricated, and equivalent circuit modelling was used to correlate structural, optical, and electrical properties.

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[2] S. Morawiec, M.J. Mendes, F. Priolo, I. Crupi, Materials Science in Semiconductor Processing 92, (2019), 10–18.
[3] S. Morawiec, J. Holovský, M.J. Mendes, M. Müller, K. Ganzerová, A. Vetushka, M. Ledinský, F. Priolo, A. Fejfar, I. Crupi, Scientific Report 6, (2016), 22481.
[4] S. Morawiec, M.J. Mendes, S.A. Filonovich, T. Mateus, S. Mirabella, H. Águas, I. Ferreira, F. Simone, E. Fortunato, R. Martins, F. Priolo, I. Crupi, Optics Express 22, (2014), A1059–A1070.
[5] S. Morawiec, M.J. Mendes, S. Mirabella, F. Simone, F. Priolo, I. Crupi, Nanotechnology 24, (2013), 265601.
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THE ROLE OF RESEARCH AND INNOVATION FOR A STRONG NATIONAL AND EUROPEANECOSYSTEM OF HYDROGEN

Giulia Monteleone

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CR Casaccia Via Anguillarese 301, 00123 Roma

Achieving the twin green and digital transitions requires a strong, integrated, and sustainable ecosystem for advanced materials. These materials are the backbone of industry competitiveness, enabling breakthroughs in clean energy technologies, sustainable manufacturing, circularity, and resource efficiency.

Advanced materials play a decisive role in energy transformation—improving the efficiency of photovoltaic cells, wind turbine blades, electrolysers, and storage systems—while reducing dependence on critical raw materials through recycling and eco-design.

Coordinated global action is essential to develop new, sustainable and not critical material, to strengthen industrial value chains, and accelerate market deployment.

Within this framework, with specific reference to development of new solutions for the hydrogen value chain, the research and innovation on new materials, assume a fundamental role.

Despite the remarkable progress we've made, continued investment in R&I remains absolutely essential. The next frontier is clear: we must make hydrogen technologies cheaper, more efficient, and more circular, while ensuring that Europe remains the world's benchmark for safety, reliability, and sustainability. It's necessary to build a strong manufacturing base for electrolysers, fuel cells, and other key components, to reduce both capital and operating costs, but at the same time it's necessary to reduce dependency on critical raw materials, replacing them with abundant, recyclable, and sustainable alternatives.

ENEA is in charge of the research activities on hydrogen in the context of PNRR, under an agreement between ENEA and the Italian Ministry of Ecological Transition. The project, which also involves CNR and RSE, intends to promote interdisciplinary and multidisciplinary interactions through the sharing of knowledge, skills, experiences, infrastructure and networks of laboratories in order to contribute to the increase of qualified critical mass and to the pursuit of objectives challenges that the PNRR aims at in the hydrogen sector. Several activities are focused on the development of new materials.

ENERGY SCENARIOS OF THE SICILIAN REGION

Roberto Sannasardo

Regional Department of Energy – Sicilian Region, Italy, Campania Avenue n. 36, 90146 Palermo

The Sicilian Region is facing the challenges arising from the implementation of the European Green Deal and is working, through a revision of its energy-planning instruments and in particular of the Energy and Environmental Plan, to achieve the ambitious 2030 targets in a context in which the region is receiving significant attention from sector operators.

The evolution of the electricity market and the new rules introduced by Decree-Law No. 210/2021 on electricity price formation are currently under way and closely monitored, given the implications that their concrete implementation may have on the social and productive fabric of the regional territory. This aspect is strongly influenced by the increase and spatial distribution—through the regulation of suitable and unsuitable areas—of renewable energy sources, not only as a means of combating climate change and achieving environmental targets, but also as a contribution to countering the depopulation of inland areas and fostering the reindustrialisation of the island's productive system.

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RETEIFV: VISION AND STRATEGIES OF THE ITALIAN PHOTOVOLTAIC R&I COMMUNITY

M. Mazzer, S. Binetti, C. Barolo, F. Bizzarri, A. Danelli, P. Delli Veneri, A. Di Carlo, M. Foti, A. Grassi, S. Guastella, M. Izzi, G. Maugeri, M. Meneghini, D. Moser, G. Spagnuolo, A. Romeo, A. Terrasi, M. Tucci

Rete Italiana Fotovoltaico per la Ricerca e l'Innovazione (ReteIFV)

The Italian Photovoltaic Network for Research and Innovation (ReteIFV) is an informal community of scientists, innovation managers, and other PV experts working to advance Italy's photovoltaic sector and support a socially and environmentally sustainable energy transition, prioritizing equity, inclusion, and diversity. Founded in 2017, ReteIFV was established to align national PV research and innovation activities with the priorities outlined in the European Strategic Energy Technology (SET) Plan. Several key national R&I projects and the national PhD programme on PV were inspired by the White Paper, the strategic document published by ReteIFV in 2020. ReteIFV is currently undergoing reorganisation to pursue more ambitious objectives on the route to fortifying Italy's leadership in photovoltaic technology and manufacturing and to contributing to Italy's transition towards a 100%-renewable and resilient energy system. As an open and dynamic platform, ReteIFV seeks to catalyse new projects and partnerships by acting as a nationwide distributed R&I lab and springboard of industrial innovation. ReteIFV is willing to support the development of innovative photovoltaic products and solutions and to promote the unfolding of new competitive Italian value chains rooted on circular economy principles. Key to this strategy is not only a strong and extensive collaboration between R&I organisations and industry but also the engagement with local communities and institutions to tackle urgent issues such as climate change, biosphere integrity, soil and landscape preservation in the frame of energy democracy. To pursue these objectives ReteIFV is willing to establish strong and systemic collaborations with experts in other fields such as climatology, ecology, architecture, agronomy, landscape design, urban and territorial planning, energy engineering, economics, environmental science, social justice, environmental and energy law, sustainability policies, and beyond.

Being a member of ReteIFV means sharing this vision and participating in the activities of the community. Individuals with skills and experience in the field of photovoltaics can also volunteer to become involved in one of the Working Groups or apply to participate in the Steering Committee of ReteIFV.

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SESSION II

GDL ENERGIA E TECNOLOGIE SOSTENIBILI & RETE ITALIANA LCA

CHAIR Sonia Longo

CHAIR Maria Laura Parisi

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PROSPECTIVE LIFE CYCLE ASSESSMENT FOR THE ECO-DESIGN OF PEROVSKITE/SILICON TANDEM SOLAR CELLS FROM THE LAB SCALE TO INDUSTRIAL SOLAR DEVICES

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In their R&D phase, perovskite/silicon tandem solar cells (TSC) have continued to demonstrate excellent power conversion efficiencies (PCEs) while promising low-cost manufacturing [1][2]. With prospects for further enhancements, this technology has been pushed closer to market entrance. Nevertheless, for a photovoltaic technology to reach commercialization, factors such as high efficiency, scalability, long-term stability, cost competitiveness, and environmental friendliness need to be considered [3][4]. This study presents a prospective life cycle assessment (pLCA) of four perovskite–silicon tandem configurations (TSC1–TSC4) projected from the present to the future (2050). The analysis integrates design adjustments to reflect scalability, considers projected operational parameters, and accounts for changes in the electricity mix within manufacturing supply chains. Environmental performance is evaluated across four indicators: global warming potential (GWP), cumulative energy demand (CED), energy payback time (EPBT), and carbon payback time (CO_2PBT). Results indicate a progressive decline in both carbon footprint and energy consumption for tandem solar technologies over time. Moreover, future TSCs are projected to outperform single-junction silicon cells in terms of environmental performance, as their higher efficiency compensates for greater production impacts, assuming equivalent lifetimes. Among the designs studied, TSC3 demonstrates the lowest environmental burden per m2, while TSC4 achieves superior environmental performance per kWh across all impact categories considered. The findings underscore that while material choices significantly influence environmental outcomes, optimizing overall device architecture to maximize efficiency is equally important for developing sustainable, high-performance tandem solar technologies.

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ASSESSING THE SPILLOVER, MULTIPLIER AND FEEDBACK EFFECTS OF LOW CARBON ENERGY TECHNOLOGIES IN ITALY

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In Europe, renewable energy already plays a major role in energy supply, supporting the Green Deal's goal to cut emissions by 50–55% by 2030 and reach climate neutrality by 2050 [1]. In this context, the study assesses the environmental, economic and social impacts of increased investments in renewable technologies in Italy, developing an integrated approach based on a Multi-Regional Input-Output (MRIO) model designed for Italy and the rest of the world [2]. This model allows the analysis of multiplier, spillover and feedback effects along value chains, showing how impacts propagate between regions as a result of the sector's transformation. The multiplier effect reflects domestic interactions, the spillover effect represents Italy's one-way influence abroad, while the feedback effect describes the reverse impact on Italy [3]. The investment scenarios focus on photovoltaic and wind technologies, crucial for achieving 2030 decarbonization goals. The study quantifies greenhouse gas emissions, value added, and employment effects: about 38% of GHG emissions from photovoltaics and 53% from wind energy occur abroad, highlighting global interconnections in renewable value chains. Conversely, most value added remains in Italy, showing a strong capacity to retain economic benefits. Employment effects are balanced across technologies, aligning Italy's energy transition with broader European decarbonization objectives.

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EARLY DESIGN EVALUATION THROUGH LIFE CYCLE ASSESSMENT AND ENVIRONMENTAL LIFE CYCLE COSTING: LESSONS FROM THE NANOSCALE ENERGY HARVESTER CASE

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As encouraged by the Ecodesign for Sustainable Products Regulation [1], sustainable product design requires integrating environmental and economic assessments from the earliest stages of product development to understand potential life-cycle benefits before market introduction. Despite uncertainties in early-stage data, life cycle thinking provides valuable insights that guide sustainable development and help mitigate unforeseen long-term impacts. This study presents lessons learned from applying early-stage evaluation approaches - combining Life Cycle Assessment (LCA) and Environmental Life Cycle Costing (eLCC) - to nanoscale spintronic energy harvesters, emerging devices that capture ambient electromagnetic energy for low-power applications. In detail, fifteen laboratory-scale configurations, varying in surface area and magnetic tunnel junction arrangements, were analyzed. The methodology included: i) hotspot analysis to identify major contributors to environmental and economic impacts, ii) sensitivity analysis to assess uncertainties related to material use and energy consumption, and iii) a comparative trade-off assessment to explore design options that balance performance and sustainability. Results show that critical materials used in the devices - such as platinum, ruthenium, and copper - are the main contributors to environmental impacts, while fabrication processes, including sputtering and lithography, account for most of the energy use and costs. Sensitivity analysis indicated that uncertainty in production process data—particularly regarding material losses and the energy consumed during sputtering—can vary impacts by up to ±20%. Trade-off evaluation identified design options that reduce impacts without compromising energy performance, highlighting potential energy savings and rapid payback times. Overall, the study demonstrates that early integration of LCA and eLCC - supported by hotspot, uncertainty, and trade-off analyses - can effectively guide sustainable design decisions, inform materials and process selection, and provide practical insights for the responsible development of nanoscale energy-harvesting devices.

This work was partially funded by the European Union (NextGeneration EU) through the MUR-PNRR project Innovation Ecosystem – Sicilian MicronanoTech Research and Innovation Center (SAMOTHRACE) (ECS00000022).

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HOW TECHNOLOGY AND INSTALLATION SHAPE THE ENVIRONMENTAL SUSTAINABILITY OF PHOTOVOLTAIC MODULES

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The energy sector is estimated to account for approximately 80% of total greenhouse gas emissions in Europe, making its transition toward renewable sources a central pillar of the European Green Deal. Among the various renewable energy options, photovoltaic (PV) systems stand out as a promising solution thanks to their scalability, cost reduction, and potential for decentralized generation. However, the production process involves energy-intensive activities, the use of scarce or hazardous materials, and the creation of waste that needs to be carefully managed. In this study, an analysis of published Environmental Product Declarations (EPDs) - third-party verified life cycle assessments compliant with ISO 14025:2006 - was conducted to estimate the average environmental profile of commercially available photovoltaic modules. Statistical analysis revealed that over 60% of the studies refer to bifacial photovoltaic modules, 63% describe modules based on TOPCon solar cells, 9% focus on heterojunction (SHJ) modules, and only 16% represent PERC modules. This distribution aligns well with trends outlined in recent ITRPV and IEA-PVPS reports, which foresee a near-future overtaking of bifacial modules and a substantial increase in the production of TOPCon and SHJ modules. To support policymakers and industry experts, it is essential to understand how installation parameters and environmental conditions influence both the carbon emission payback time and the overall environmental performance of photovoltaic installations. The analysis examined the effects of tilt angle, azimuth orientation, and bifacial gain under controlled conditions, monitoring how these factors modify the environmental profile based on simulated energy output over a 25-year service life. The results indicate a 16% reduction in environmental impact between the worst (0°) and best (39°) tilt angle scenarios, and a decrease of more than 30% when comparing south-facing to west-facing installations. Moreover, a 20% increase in electricity generation due to bifacial gain was estimated to correspond to a 16% reduction in the associated environmental impact. Lastly, the greenhouse gas (GHG) emission payback time for PV modules alone was found to be approximately one year.

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THE ASSESSMENT OF THE LIFE-CYCLE ECONOMIC AND SOCIAL IMPACTS OF HGRSS: THE EXPERIENCE OF THE FUD-OF SITHY PROJECT

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Among soil-less systems, Hydroponic Green Roof Systems (HGRSs) belongs to the Building Integrated Agriculture concept, which is a sustainable strategy for urban food produc-tion that can reduce environmental footprint, cut transportation costs, enhance food secu-rity/safety, increase the building thermal insulation, thus contributing to the energy saving for space heating and cooling. In this context, the study aims at evaluating economic and social as-pects of HGRSs installed on building rooftops in the Mediterranean region hydroponic systems. A case study is applied to a small pilot hydroponic plant located in Reggio Calabria. Economic and social analyses are performed, to identify specific 'hot spots' and, consequently, actions to improve the overall sustainability and circularity of the whole system. The results of the study can help to promote economically and socially sustainable food supply chains within a circular economy framework. The study is developed within the project "FUD-OF-SITHY - Favor the Urban Development OF Sustainable agrIculture Through Hydroponics" funded by European Un-ion- Next Generation EU, Mission 4 Component 1 (Project CUP B53D23027030001).

ENVIRONMENTAL IMPACTS OF HGRSS: THE EXPERIENCE OF THE FUD-OF-SITHY PROJECT

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The promotion of soil-less cultivation systems represents a promising alternative to conventional agriculture, offering opportunities to enhance food security and reduce environmental pressures in urban areas. Within this context, the present study explores the energy and environmental implications of implementing Hydroponic Green Roof Systems (HGRS) on building rooftops across the Mediterranean region. Using the Life Cycle Assessment approach, a case study is conducted to quantify the potential performance of these systems in terms of energy use and environmental impact associated with urban food production. The findings highlight the components and materials that contribute most significantly to the overall impacts, with the water tank and supporting platform emerging as the main hotspots. These insights provide valuable guidance for developing future eco-design strategies aimed at improving the sustainability of hydroponic roof systems. The study is developed within the project "FUD-OF-SITHY - Favor the Urban Development OF Sustainable agrIculture Through Hydroponics" funded by European Union- Next Generation EU, Mission 4 Component 1, CUP B53D23027030001.

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SESSION III

INNOVATIVE TECHNOLOGIES AND SUSTAINABILITY FOR PHOTOVOLTAICS

CHAIR Marco Cannas

EMERGENT PROPERTIES FROM NANOCRYSTAL SUPERSTRUCTURES

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Semiconductor nanocrystals (NCs) exhibit quantum confinement effects that lead to highly tunable optical and electronic properties. This unique versatility has positioned NCs as key components for next-generation optoelectronic and photonic technologies. By controlling their size, shape, and composition, researchers are working toward a new "periodic table" of artificial atoms, enabling the rational design of materials from the bottom up.[1] A major challenge - and opportunity! - lies in directing the assembly of these NCs into ordered superstructures that exhibit emergent, collective properties. Such artificial solids hold promise for applications ranging from light management to low-threshold lasing and energy-efficient photonic systems. However, the deterministic control of NC self-assembly remains limited by an incomplete understanding of interparticle interactions.[2]
In this talk, I will present a general strategy to bias the self-assembly of NCs into three-dimensional superstructures with well-defined morphology and high crystalline order. Using emulsion-templated assembly, we guide the formation of spherical supercrystals composed of densely packed, ordered NCs.[3] Time-resolved synchrotron X-ray scattering reveals a ligand-mediated hard-sphere-like crystallization mechanism,[4] yielding single-domain architectures approaching single-crystal quality.[5]
These superstructures exhibit multiscale optical functionality: while their refractive index is determined by the nanocrystal composition, their mesoscale geometry supports Mie resonances, leading to enhanced absorption and scattering.[6] Post-assembly ligand exchange strengthens interparticle coupling, enabling the emergence of whispering gallery modes that confine light along the surface of the superstructure,[7] leading to cross-talk phenomena in superstructure clusters.[8] This optical feedback triggers low-threshold lasing, with emission spectra tunable by optical[9] and dielectric[10] stimuli.

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SUSTAINABILITY IN PHOTOVOLTAICS

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As photovoltaic technologies become central to Europe's decarbonization pathway, their environmental sustainability is gaining unprecedented attention. The Life Cycle Assessment has evolved from a methodological tool to a key driver of industrial policy and regulation, directly influencing incentives and market access under frameworks such as the EU Net Zero Industry Act.
This presentation will explore how technological innovation and manufacturing choices determine the carbon footprint of PV modules, with particular focus on the influence of the electricity grid mix, material composition, and module durability. It will also address critical aspects such as Energy Payback Time, and discuss emerging sustainability challenges including material scarcity, PFAS use, and end-of-life recovery.
Drawing on the perspective of the PV manufacturing industry, the talk will highlight how reducing the carbon footprint through responsible sourcing, design optimization, and circularity can reinforce both environmental integrity and European industrial resilience.

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GIGAWATT-SCALE SOLAR IN EUROPE: OVERCOMING CHALLENGES AND DRIVING HJT & TANDEM INNOVATION

Marina Foti

3SUN - Contrada Blocco Torrazze - Zona Industriale, Italy, Catania

Scaling high-efficiency photovoltaic (PV) technologies to gigawatt-level production in Europe is both a technical challenge and a strategic imperative for energy sovereignty. Silicon heterojunction (HJT) solar cells, with their superior efficiency and bifacial potential, are a frontrunner for next-generation PV. Yet, industrializing HJT at giga scale demands breakthroughs in process control, equipment performance, and sustainable material sourcing—critical areas where materials science and advanced automation play a pivotal role.

This presentation will explore the challenges and opportunities in scaling HJT manufacturing, highlighting innovations in transparent conductive oxides, passivation layers, and metallization, as well as AI-driven process optimization to boost throughput and yield. In parallel, we will present our progress on tandem architectures combining HJT with perovskite top cells, aiming to surpass 30% efficiency and enable industrial deployment within the next few years.

A key focus will be on Intellectual Property (IP) considerations for HJT technology, addressing how proprietary process know-how and patent strategies shape competitiveness and protect innovation in a rapidly evolving PV market.

Additionally, the current status of 3SUN's gigawatt-scale factory will be shared, showcasing milestones in production capacity, technology integration, and steps toward a resilient European PV value chain.

By bridging scientific innovation, IP strategy, and industrial execution, 3SUN is pioneering scalable, high-efficiency solar manufacturing and accelerating Europe's clean energy future.

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ENVIRONMENTAL IMPACTS OF PEROVSKITE SOLAR CELLS: AN ANALYTICAL APPROACH

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Organic–inorganic hybrid perovskite solar cells (PSCs) are a groundbreaking photovoltaic (PV) technology, reaching conversion efficiencies higher than 25 %. The solution-based processability, their flexibility and semitransparency allow them to be a paradigm changer in the field [1]. However, PSC photovoltaics still struggles to compete with silicon-based devices, mainly due to the still poor stability under ambient conditions. A typical approach for improving perovskite stability consists in introducing additives to improve the perovskite crystallinity. For instance, a PSC photoconversion efficiency (PCE) improvement can be obtained by adding minimal 5 mg/mL concentrations of a natural additive (α-terpineol) to control the crystallization of $CH_3NH_3PbI_{3-x}Cl_x$ perovskite cristals films [2]. Given that α-terpineol has a higher boiling point with respect to N,N-dimethylformamide perovskite solvent, larger and ordered perovskite crystals could be obtained, leading to an improved PCE (17.5% vs. 16.1%). A part from typical I-V curves, PSCs devices stability can be studied under non steady state conditions and pollutants leaching after operation. To this aim, two electroanalytical tools can be employed, namely the Anodic Stripping Voltammetry (ASV) and the Electrochemical Impedance Spectroscopy (EIS). ASV allows for the detection of metal ions leached from the PSC by quantifying the electrical current during the "stripping" step of analytes previosuly electrodeposited on the working electrode [3]. Differently, EIS is based on the frequency dependent PSC perturbation by a sinusoidal oscillating voltage applied in addition to a DC voltage, to measure an output current under dark or light stimulation [4]. As an example, by employing ASV detection of leached ions following the standard UNI EN 12457–2, hydrophobic additives such as perfluorinated pyrene compounds added in the Spiro-OMeTAD Hole Transport Layer, can reduce lead release from perovskite solar cells by approximately 45 %, compared to conventional perovskite solar cells [5]. To further corroborate these findings, structure-function relatioships can be invesigated by EIS, allowing providing a complete *in-operando* analysis of the device processes.

Acknowledgments: Financial support from MUR is acknowledged under the project “ROBERTA-integrated Approach to Real Eco Sustainable Green Total Index” CUP E53D23015670001, project number P2022HEBEX funded by EU in Next Generation EU plan through the ITALIA “PRIN 2022 PNRR” finanziato dall’Unione Europea. Advanced Technologies Network (ATeN) Center is also acknowledged for hospitality and service.

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SESSION IV

SPOKE 1

CHAIR Michela Chimienti

CHAIR Maurizio Cellura

ENHANCING THE PERFORMANCE OF SB_2SE_3 THIN-FILM SOLAR CELLS: STRATEGIES FOR OPTIMIZATION AND THE ROLE OF ADVANCED CHARACTERIZATION

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Antimony selenide (Sb_2Se_3) is attracting increasing attention as a low-toxicity and earth-abundant absorber material for thin-film solar cells. Its suitable bandgap, high absorption coefficient, and nearly defect-free grain boundaries make it an appealing alternative to CdTe and CIGS technologies. However, the strong structural anisotropy and low intrinsic carrier density still limit its photovoltaic performance.
This work explores strategies to overcome these limitations through controlled thin-film growth, dopant engineering, and advanced nanoscale characterization. Thin films of Sb_2Se_3 and Cu-doped Sb_2Se_3 were deposited by Low-Temperature Pulsed Electron Deposition (LT-PED) and RF-Magnetron Sputtering, varying deposition parameters and substrate treatments to promote favorable crystalline orientation. Doping with Cu and Na was investigated to increase p-type conductivity, while XRD, Raman, and SEM analyses correlated texture, morphology, and composition. Complementary conductive-AFM and Tip-Enhanced Raman Spectroscopy (TERS), performed in collaboration with ETH Zurich, enabled nanoscale mapping of local conductivity and interfacial chemistry, revealing dopant distribution and recombination pathways. In parallel, degradation studies under monochromatic light soaking, conducted in collaboration with the University of Padova, highlighted metastable behavior linked to trap-state formation and charge recombination, providing essential insights into the stability and reliability of Sb_2Se_3-based devices. Finally, SCAPS-1D simulations guided the design of Cd-free architectures incorporating ZnSnO (ZTO) as electron transport layer and MoO_x as hole transport layer. This integrated approach demonstrates that the combination of deposition optimization, targeted doping, degradation analysis, and advanced characterization provides a deeper understanding of the material's intrinsic properties and the underlying doping mechanisms, thereby paving the way for the rational design of more efficient and sustainable photovoltaic technologies.

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RECYCLING ALONG THE PV PRODUCTION CHAIN, INCLUDING RESULTS FROM PHOTORAMA AND ICARUS EU PROJECTS

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What began as an idea in December 2019 has grown into a driving force for innovation in photovoltaic recycling. Across the entire production chain, we explore and process material flows—using methods that unite physics and chemistry in novel ways. Our technologies are homegrown, born of curiosity and a desire for transformation. The EU-funded projects Photorama [1] and Icarus [2] stand as milestones in this journey, and we are proud to share their outcomes. Material closed-loop systems will allow a circular economy for silicon ingot and wafer manufacturers, potentially unlocking substantial volumes of raw materials for further industrial high-end applications. We also offer innovative approaches for other production and end-of-life waste streams. Our work includes processing discarded photovoltaic modules and transforming them into marketable products, demonstrating the full potential of circular value creation.

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PHOTOCONDUCTIVITY AND STABILITY OF 2D PEROVSKITES: EXPLORING LEAD AND TIN-BASED MATERIALS FOR FUTURE OPTOELECTRONIC AND NEUROMORPHIC APPLICATIONS

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Two-dimensional (2D) perovskite semiconductors are emerging materials for next-generation optoelectronic devices due to their tunable properties and environmental adaptability. This study examines two materials: $(PEA)_2PbI_4$ and $(PEA)_2SnI_4$, both offering promising features for diverse applications. For $(PEA)_2PbI_4$, synthesized using a space-confined growth technique, the device exhibits excellent photoresponse under broadband white light, with ultra-low dark current (10^{-14} A), and high specific detectivity (10^9 Jones). The temperature and wavelength dependence of the photocurrent suggests exciton dissociation as a key mechanism, alongside strong stability under air and light exposure [1]. In contrast, $(PEA)_2SnI_4$ devices show strong visible light absorption and favorable charge transport, with a sublinear power dependence, indicating trap-assisted photoconductivity. Temperature-dependent measurements reveal a transition from trap-limited conduction to phonon- and ion-migration-limited conduction [2]. These findings highlight the potential of 2D perovskites for advanced optoelectronic and neuromorphic systems.

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MOLTEN SALT STORAGE AS AN ENERGY HUB FOR THE ENERGY TRANSITION

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The use of molten salts as heat storage media has been one of the important outcomes of the CSP industry. The emergence of power to heat (P2H) technologies and Carnot battery concepts, provides the framework for a wider perception of Molten Salt based storage technologies as a "energy hub" enabling the integration of different primary energy sources and the delivery of final energy vectors:

- relying on abundant materials such as steel, nitrate salts, thermal insulation, heat tracing elements, which compares to the heavy dependence of Li-Ion batteries on Critical Raw Materials;
- based on well established EU industrial competencies, capacity and value chains, which compares to the extremely strong prominence of China in the Li-Ion supply chain;
- reduced degradation over time, when compared to “clock ticking” degradation of Li-Ion batteries rendering halved lifetimes;
- presenting decade long operation track record in large capacity (GWh scale) storage systems, compared to the relatively recent track record of large scale Li-Ion battery based large capacity systems;
- presenting the ability for charging and discharging across different energy vectors (electricity or heat), thus presenting sector-coupling potential out of reach with the electricity only operation of Li-Ion batteries,

Within the scope of project SALTopower, an extended vision of a Molten Salt based energy hub further enabling the thermal supply to thermochemical reactions, further deepens its sector coupling potential and enables additional options to the full exploitation of their potential in terms of flexibility, cost, reliability or security of supply.

Based on this "beyond state-of-the-art" vision, SALTpower further enabled the adaptation of INIESC' Évora Molten Salt platform facility to the ensuing implementation of system components in both applied research or industry service activities enabling the future demonstration of this concept, in promotion of a wider role for this technology in the framework of the Energy Transition.

SESSION V

SPOKE 9

CHAIR Gabriella Scapicchio

CHAIR Simona Barison

PHOTOANODIC INTERFACES FOR APPLICATIONS RELEVANT TO SOLAR FUELS PRODUCTION

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The exploitation of renewable energy sources (such as sunlight), striving to produce alternative fuels, is one of the most pursued strategies to relieve the global energy thirst. With this aim, a viable but challenging approach consists in the development of photoelectrochemical cells.[1] These devices mimic the natural photosynthesis by storing solar energy as chemical energy in value-added compounds produced at two separated electrodes.
In this contribution we will report on different kinds of photoactive interfaces (namely hematite-based and dye-sensitized photoanodes) and their application in processes relevant to solar fuels production. In particular, hematite photoanodes were prepared via hydrothermal synthesis in the presence of a Ti(IV) precursor belonging to the family of MXenes, i.e. two-dimensional materials with general formula $M_{n+1}X_nT_x$ (where M is an early transition, X is C and/or N, and T is a terminal surface group), recently reported to improve the performances of perovskite solar cells by inducing the formation of an interface dipole and tuning the interfacial band alignment.[2] The MXene-modified photoanodes showed a significant improvement in terms of photocurrent (up to 3.0 mA/cm^2 at 1.85 V vs RHE) when compared to Hematite electrodes not including such precursor in the synthetic route. Electrochemical Impedance Spectroscopy and morphologic data will be discussed in order to unravel the charge transfer/transport mechanisms and the structural effects behind such improvement. Preliminary results on the use of these photoanodes in combination with gas diffusion electrodes for CO_2 reduction will be also discussed. As regards the dye-sensitized photoanodes, we will report on the functionalization of high band gap semiconductors with novel sensitizers based on Ru(II)-polypyridines, evidencing the generation of sizable photocurrent due to reductive quenching.[3] Preliminary results on the introduction of molecular catalytic units on such interfaces will be also discussed.

We acknowledge financial support by the Italian Ministry of University and Research (MUR) under the National Recovery and Resilience Plan, funded by the European Union – NextGenerationEU (Project Title: Decoupled production of solar fuels - Leaf, Prot. P20229L2EE) and under the PRIN2022 project “Photogen” (Prot. 2022AWXS83)

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TAILORING METAL EXSOLUTION IN DOPED OXIDES

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Exsolution has recently gained attention as a versatile method for decorating functional oxides with catalytically active nanoparticles, providing a pathway to robust, multifunctional materials for energy-conversion devices including solid oxide cells, electrolysers, catalysts, and gas-separation membranes. In this work, the co-doping with noble and transition metals (M = Pt, Pd, Fe, Cu, Ni) of yttrium-doped barium cerate–zirconate ($BaCe_xZr_yY_zM_{1-x-y-z}O_{3-\delta}$) [1] and gadolinium-doped ceria ($Ce_xGd_yM_{1-x-y}O_{2-\delta}$) [2] was investigated. The resulting powders and sintered pellets were characterized using XRD, SEM-EDX, ICP-OES, and TG-DSC analyses. The exsolution behaviour of these materials was systematically studied at different temperatures (600, 750, and 900 °C) under reducing conditions, to correlate the dopant identity and stoichiometry with nanoparticle nucleation, growth, and distribution. Preliminary conductivity measurements, and anelastic and dielectric spectroscopies were performed on $BaCe_{0.7}Zr_{0.1}Y_{0.15}Ni_{0.05}O_{3-\delta}$ for the first time to probe the dynamic response of the lattice to stress perturbations and dielectric relaxation. The combination of these techniques provides deeper insights into the interplay between defect chemistry, transport properties, and nanoparticle exsolution. Because Ba-based perovskites such as BCZY suffer from CO_2-induced degradation, the carbonation resistance of doped and exsolved $BaCe_xZr_yY_zM_{1-x-y-z}O_{3-\delta}$ was also evaluated. Furthermore, $BaCe_xZr_yY_zM_{1-x-y-z}O_{3-\delta}$ was implemented as a catalyst for ammonia cracking, and the influence of synthesis method and calcination temperature is currently under investigation. Overall, this work establishes clear correlations between doping strategies, exsolution-driven nanostructuring, and functional performance, providing guidelines for tailoring host–dopant interactions to achieve stable, finely dispersed nanoparticles—paving the way for next-generation energy conversion devices.

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NEST NETWORK FOR ENERGY SUSTAINABLE TRANSITION

CARBON-BASED HIERARCHICAL NANOSTRUCTURES FOR ELECTROCATALYSIS

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Integrating nanocarbons into hierarchical materials has previously emerged as an effective strategy to enhance the potential of nanostructured catalysts, especially in water splitting and oxygen reduction reaction contexts. In this regard, the electrocatalytic properties of metals and metal oxides can be dramatically enhanced when electronically coupled to carbon nanotube/graphene scaffolds [1,2].
In the context of HER and CO2RR, the synergistic effect arising from the formation of suitable carbon-inorganic interfaces, where the carbon nanostructures (CNSs) can improve charge transfer at the metal/metal oxide interface, enhance catalyst stability and facilitate reactant diffusion to the active site, enhancing CO2 adsorption capacity [3-5]. Integrating CNSs into carbon/metal oxide nanocomposites can trigger a series of events, making the catalytically active site functional at lower onset potentials and increasing selectivity toward HCOOH, alcohols and C2+ chemicals, appealing CO2RR products that can be used as a fuel or a hydrogen source through catalytic decomposition [6].

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FROM EARTH TO ENERGY TRANSITION: GEOTHERMAL SYSTEMS, CRITICAL RAW MATERIALS AND MINERAL CARBONATION

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The transition toward a low-carbon energy system relies on an advanced understanding of subsurface processes, where renewable heat, strategic mineral resources and long-term carbon storage potentials spatially and chemically interact. Geosciences therefore constitute a foundational component of the energy-transition toolbox, providing the observational, analytical and modelling frameworks required to support electrification, decarbonization and system resilience. This contribution illustrates how integrated geological, geochemical and geophysical approaches can address three central pillars of the transition: geothermal energy, critical raw materials and Carbon Capture and Mineral Storage (CCMS).

Recent advances in the characterization of high- and medium-enthalpy geothermal systems demonstrate how petrology, structural geology and fluid–rock interaction studies can improve resource assessment, reservoir conceptualization and the design of innovative and sustainable exploitation strategies [1]. In parallel, the rapidly increasing demand for critical minerals essential to photovoltaics, electrochemical storage and low-impact technologies requires new predictive exploration models capable of identifying favourable geological environments, including deep-seated, unconventional [2] or previously overlooked mineral systems. CCMS represents a complementary pathway for permanent CO_2 immobilization, leveraging naturally occurring mineral carbonation reactions within ultramafic, basaltic and reactive sedimentary lithologies to achieve long-term geochemical stability [3].

By emphasizing synergies among these domains, the presentation will discuss how geoscience-driven innovation can inform robust, environmentally constrained strategies for the sustainable use of the subsurface, while aligning with the principles of the European Green Deal. Addressing these challenges demands a genuinely systemic and interdisciplinary approach that integrates geoscientists, engineers, chemists and physicists, together with non-scientific stakeholders involved in resource governance and societal uptake.

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SESSION VI

Bandi a Cascata (BAC)

SPOKE 6-7-8

CHAIR Francesco Guarino

NANOSTRUCTURED PHOTO/ELECTRO COMPOSITES FOR THE PRODUCTION OF H_2 AND HIGH ADDED-VALUE CHEMICALS BY WATER SPLITTING AND CO_2 REDUCTION (NANO-PLUS)

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The Nano-Plus project aims to develop titania-based composite photocatalysts and electrodes engineered with carbon dots (CDs) for the photo/electrocatalytic production of hydrogen (H_2) and the reduction of carbon dioxide (CO_2) into formic acid, methane, and methanol. The project investigated a range of titania catalysts with different morphologies, structures, and optoelectronic properties, combined with various types of CDs derived from atmospheric plasma, to identify the most effective titania/CD combination.

For the most promising catalysts and electrodes, process scalability has been studied to define a final product suitable for pre-industrial scale-up and testing. The materials under investigation are non-critical and produced through low-energy processes, ensuring both environmental and process sustainability.

The project partnership, Ca' Foscari University of Venice and University of Trieste, combines complementary expertise and long-standing experience in advanced materials and process development for sustainable energy conversion. The consortium is equipped to address all project dimensions, from fundamental research (low TRL) to process scalability (intermediate TRL) and technology transfer, acting as a catalyst for the transition of project outcomes toward market application. Thanks to the industrial experience of ChEERS srl and Nadir srl partners, Nano-Plus has contributed to develop an exportable scalability model, maximizing the impact and effectiveness of the results, in full alignment with the objectives of the funding program.

In addition to its scientific and technological achievements, the project has placed strong emphasis on extensive dissemination and outreach and public engagement, successfully raising awareness about the development and real-world applicability of innovative technologies for the sustainable production of hydrogen and other solar fuels. Through a range of targeted activities, the project has reached diverse audiences, from the scientific community to general public to industry professionals, fostering greater understanding and dialogue around clean energy solutions.

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TRACKING SYSTEM WITH THIN-FILM PV TECHNOLOGY FOR RESILIENT AGRICULTURE: THE RESULTS OF LIFE AGRO-PV

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This paper describes the operation and the first monitoring results of the experimental agrivoltaic plant installed at La Collina Bio farm in Carlentini, as part of the LIFE AGRO-PV project. The installation uses three types of flexible photovoltaic modules – two in silicon and one CIGS – installed via a metal superstructure on the roof of a greenhouse. The configuration induces partial shading of crops, thus allowing the impact of sunlight on plant growth to be tested. Three sectors of the superstructure are mobile and are automatically regulated by electric motors based on the environmental parameters detected, while the others are fixed: this makes the agrivoltaic system able to adapt to the needs of crops and energy production. Power optimizers allow monitoring electricity production, globally and for each module; in addition, a network of sensors collects data on temperature, humidity, photosynthetically active radiation (PAR) and thermophysical parameters of the soil. The monitoring activities also concern the growth of two distinct plant species (*Lactuca sativa* and *Spinacia oleracea*). The experimental system was completed in July 2025, demonstrating the technical feasibility of the solution. Monitoring activities have shown that mobile photovoltaic modules allow an increase in electricity production of about 18% compared to what is obtained with fixed modules in a horizontal position, a value that could increase by optimizing solar tracking. The presence of PV modules on the greenhouse also stabilized microclimatic conditions and improved the photochemical efficiency of the leaves, while full sun conditions maximized biomass accumulation. These results suggest that the optimal balance differs between species, with lettuce benefiting from partial shading and spinach favouring higher irradiance.

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RE.S.T.O.RE. P.V.P.: SUSTAINABLE DEMANUFACTURING OF CRYSTALLINE SILICON PHOTOVOLTAIC PANELS THROUGH CRYOGENIC DELAMINATION AND SELECTIVE LEACHING

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The rapid growth of photovoltaic (PV) installations is creating a significant end-of-life management challenge. By 2030, Italy is expected to generate 50,000–100,000 tonnes of discarded PV panels annually, yet advanced recycling capacity remains limited, particularly in Southern Italy despite its high PV density. Classified as WEEE, PV modules contain valuable materials such as silicon, copper, silver and aluminium, mostly sourced outside Europe. Their multilayer structure—comprising glass, EVA, silicon cells, backsheets and metalcomponentsrenders traditional recycling inefficient and often economically unfeasible, leading to downcycling or landfill disposal. The Re.S.T.O.Re-PVP project (Recycling Sustainable Thermo-mechanical demanufacturing Operation for Renewable PhotoVoltaic Panels) is based on the hypothesis that a sustainable continuous-flow demanufacturing process can increase recovery efficiency while reducing the environmental impacts associated with current disposal practices. The transition from batch to continuous operations is expected to enable industrial scalability and economic viability within a circular economy framework. An integrated continuous-flow process combining two complementary sections was developed and validated. The first section employs cryogenic delamination through thermal shock with liquid nitrogen at −196 °C (±3 °C) to embrittle polymers and separate layers without damaging the cells. The second section applies a three-stage selective hydrometallurgical sequence: leaching of base metals (Sn, Pb, Al) with natural acids at 80–100 °C; copper and silver separation via ammoniacal leaching under oxidising conditions at room temperature; and final refining through chemical cementation or electrowinning. A fourth stage regenerates reagents in a closed-loop cycle. The process was validated through 10 consecutive test runs on crystalline silicon panels aged 15–25 years. Recovery yields above 99% for copper and 85% for silver were achieved by the demonstrator. Ammonia recovery reached 95–98%, supporting at least three reuse cycles without performance degradation. Delamination efficiency exceeded 90%, energy consumption remained below 0.5 kWh per treated panel and cycle times ranged between 15 and 20 minutes. System uptime reached 87%, exceeding the 85% industrial reference threshold. Correlation between FEM numerical models and experimental results exceeded 95%, confirming predictive reliability for scale-up. Process automation reached 90%, reducing operator-dependent variability. The process contributes directly to NEST Spoke 1 by improving PV lifecycle sustainability through high-value material recovery. The closed-loop architecture reduces operating costs by approximately 40% compared to linear approaches and is designed for modular replication across scales. The technology supports reshoring of recycling activities currently performed outside Europe, strengthens regional development in Southern Italy and aligns with EU WEEE and Critical Raw Materials policies. With an estimated addressable market of €20–40 million per year in Italy and growing industrial interest, the Re.S.T.O.Re-PVP process is positioned as a key enabling technology for the emerging photovoltaic circular economy in Southern Europe.

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EXPLORING THE POTENTIAL OF URBAN AQUIFERS FOR SEASONAL THERMAL STORAGE

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District heating systems are key infrastructures in the transition toward low-carbon energy systems, and their decarbonization can be supported by the integration of renewable and low-temperature heat sources. Among these, shallow urban aquifers can act as subsurface reservoirs for thermal energy, enabling seasonal thermal storage. In cities such as Turin, open-loop geothermal heat pumps already interact with these aquifers: the excess heat rejected by the heat pump condenser during summer is discharged into the groundwater, increasing its temperature. This thermal perturbation, however, is currently unused: after the cooling season, the stored sensible heat dissipates within the aquifer. Recovering this heat could provide a renewable heat source during winter. Moreover, additional renewable or waste heat, such as from solar collectors or data centers, could be injected into the aquifer, offering a sustainable and space-efficient alternative to conventional surface storage systems. In moving aquifers, tracking the thermal plume generated by summer heat injection becomes essential to identify suitable areas for heat extraction during the heating season. To this end, a thermo-fluid dynamic model is adopted to evaluate the spatio-temporal evolution of the thermal perturbation and assess the technical feasibility and efficiency of aquifer thermal storage systems. In the scope of Spoke 6 (Tasks 6.1 and 6.3), numerical modelling is supported by an experimental installation aimed at analyzing the coupling with district heating networks to promote the integration of renewable energy in urban areas.

When integrated with heat pumps connected to the existing district heating network, such as the large system in Turin, the proposed aquifer thermal energy storage concept can provide a reliable and sustainable heat source during winter. This approach represents a promising step toward the decarbonization of district heating and, more broadly, of the urban energy system as a whole.

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THE ACID/BASE FLOW BATTERY: AN INNOVATIVE SALINITY AND PH GRADIENTS STORAGE DEVICE

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The Acid/Base Flow Battery (ABFB) is an electrochemical energy storage system based on a reversible electrodialytic technology that utilizes anion exchange membranes (AEM), cation exchange membranes (CEM), and bipolar membranes (BPM) [1]. To date, the ABFB is the only system reported in the literature capable of storing energy in the form of both salinity and pH gradients. Energy is stored by generating acidic and alkaline solutions during the charging phase through the Electrodialysis with Bipolar Membranes (EDBM) process, and subsequently recovered during the discharging phase via the controlled neutralization of these solutions using the Reverse Electrodialysis with Bipolar Membranes (REDBM) process. As part of the activities carried out within SPOKE 6 of the NEST Project at the University of Palermo, both experimental and modeling research have been conducted. The main objective was to identify optimal operating conditions and geometric configurations that could enhance the system's performance. From a modeling perspective, two approaches were adopted: (i) a simplified model to describe the electrical behavior of the battery with low computational cost, and (ii) an advanced multi-scale model capable of predicting all key process variables, including ionic fluxes, concentration profiles, and electric potential distributions [2]. The main phenomena limiting the battery's performance were identified, and a mitigation strategy was developed [3]. Both models were validated against experimental data collected from lab-scale ABFB units assembled with various types of ion-exchange membranes. In addition, experimental tests were conducted to investigate ion transport behavior under multi-ionic conditions, such as those found in real saline feeds (e.g., seawater or desalination brines) [4]. Further testing is currently underway to increase the energy density and reduce the overall footprint of the ABFB system, with the ultimate goal of making it a competitive solution in the energy storage market.

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SMART SECTOR INTEGRATION AND SUSTAINABILITY

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Sustainability is investigated across a multidimensional framework in Spoke 7. Task 7.4.1 addresses Economic Sustainability, analyzing commercial feasibility, the cost-benefits of smart grid digitalization, and the development of new business models for Renewable Energy Communities (RECs), hydrogen, and biomethane.

Task 7.4.2 is dedicated to Environmental Sustainability, applying the Life Cycle Assessment (LCA) methodology to quantify the carbon footprint and energy duty in agro-industrial processes and biofuel supply chains. Implementation constraints are managed by Task 7.4.3, which analyzes the Legal-Regulatory trends of the European Union, including key documents like REPowerEU and the RED III Directive, focusing on the regulatory aspects of sector coupling and Power-to-X technologies.

Finally, Task 7.4.4 focuses on Social Sustainability, assessing public awareness and acceptance of the energy transition through the analysis of case studies and the development of digital platforms for citizen involvement and the provision of real-time energy data (T7.3.3). The integration of these analyses ensures that technological innovations are holistically sustainable and ready for deployment.

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ENVIRONMENTAL SUSTAINABILITY AND ENERGY EFFICIENCY IN BUILDINGS: THE NEST EXPERIENCE

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Designing new, energy-efficient buildings and renovating existing buildings are strategic objectives both to fight climate change and to promote a more responsible use of the planet's natural resources. Sustainability of the built environment is not just a matter of energy savings, but an integrated approach that considers the entire life cycle of the building: from the choice of materials to water management, from the orientation and thermal insulation to ease of maintenance and the possibility of recycling components.

Among the most effective strategies for improving the energy efficiency of buildings are bioclimatic design, which pays greater attention to the local climate, and the adoption of advanced technologies, such as more efficient thermal insulation systems and the use of high-performance windows. Furthermore, technologies for producing energy from renewable sources, such as photovoltaic panels, solar thermal collectors, and geothermal heat pumps, reduce dependence on fossil fuels and facilitate the achievement of the nearly zero-energy building (nZEB) target.

Given the multitude of possible interventions and the resulting large number of variables to consider, the use of optimization techniques is essential to identify the best interventions to adopt for each climate context and building type.

The study, conducted as part of the Spoke 8 of NEST project, aims to identify the most appropriate strategies to identify the optimal combination of the various possible energy retrofit interventions, specific to the climate context and building type analyzed. In short, the goal is to improve the energy efficiency of the building stock based on the LCA methodology, synergistically integrating the closely linked environmental, energy, and economic aspects.

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Poster Contributions

PROBING REVERSE-BIAS EFFECTS IN WIDE-BANDGAP PEROVSKITE SOLAR CELLS USING SPECTROSCOPIC TECHNIQUES

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In the field of the green energy transition, solar technologies are experiencing rapid growth, pushing the search for materials capable of achieving higher power conversion efficiencies at lower fabrication costs. Among these, lead halide perovskites have emerged as highly promising candidates thanks to their strong optical absorption, adjustable bandgap, and cheap fabrication compared to conventional photovoltaic materials. However, the commercialization of perovskite solar cells (PSCs) is hindered by several issues, such as limited operational stability. Indeed, these devices can degrade through multiple mechanisms, including exposure to moisture or heat, photochemical reactions, and electrical stress. Focusing on the last, electrical stress—often triggered by reverse bias—can promote ion-vacancy migration within the perovskite structure, resulting in permanent structural and electronic alterations. This work examines reverse-bias-induced degradation in wide-bandgap formamidinium lead bromide ($FAPbBr_3$) PSCs. Raman spectroscopy is here employed to detect and quantify structural modifications associated with ion-vacancy migration under reverse electrical polarization. Its non-destructive nature and high spatial resolution enable the identification of subtle lattice changes linked to early-stage degradation. To further connect structural evolution with device performance, we also perform steady-state and time-resolved photoluminescence measurements.
By integrating spectroscopic observations with I-V behaviour, this study offers deeper insight into degradation pathways—particularly those initiated by electrical stress—and underscores the value of spectroscopic techniques in improving the stability and long-term reliability of perovskite solar cells.

Acknowledgment: This work has been developed in the framework of the project "Network 4 Energy Sustainable Transition – NEST", code PE0000021, CUP B73C22001280006, Spoke 1, funded under the National Recovery and Resilience Plan (NRRP), Mission 4, by the European Union – NextGenerationEU.

PERFORMANCE EVALUATION OF A FINNED BAR-AND-PLATE LATENT THERMAL ENERGY STORAGE FOR SOLAR THERMAL APPLICATIONS

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Latent thermal energy storage (LTES) systems employing phase change materials (PCMs) provide an effective solution to compensate for the intermittent and unstable nature of thermal energy sources, such as solar energy. However, the inherently low thermal conductivity of PCMs represents a significant limitation, resulting in reduced heat transfer rates and extended charging and discharging times. Such limitations can be addressed either by enhancing the thermal conductivity of the PCM or by carefully optimizing the geometry of the storage system. In this work, a finned bar-and-plate LTES unit was experimentally investigated using PCM RT42 (paraffin wax, 38-42 °C melting temperature range). The experimental campaign considered variations in heat transfer fluid (HTF) mass flow rate (100, 150 and 200 kg h^{-1}) and inlet temperature (46, 49 and 52 °C), corresponding to driving temperature differences ΔT_{th} (HTF inlet-to-upper melting temperature difference) of 3, 6 and 9 °C. Results indicate that both high ΔT_{th} and HTF mass flow rate values significantly accelerate melting: increasing ΔT_{th} from 3 °C to 9 °C at 200 kg h^{-1} reduced the melting time by 53%, whereas raising mass flow rate from 100 to 200 kg h^{-1} at ΔT_{th} = 9 °C led to a 36% reduction. To complement the experimental investigation, a resistance-capacitance numerical model of the LTES unit was developed, capturing the transient thermal behavior and enabling accurate predictions of melting times (with 6% maximum deviation between experimental and numerical values). The validated model was then employed to conduct a parametric study investigating the potential use of erythritol as an alternative PCM for coupling the LTES unit with a solar concentrator in medium-temperature applications. The findings provide a robust framework for the optimal design of LTES units and their integration with solar concentration systems.

Finanziato dall'Unione europea NextGenerationEU
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NEST Network for Energy Sustainable Transition

GRAPH-BASED NEURAL ARCHITECTURES FOR ACCURATE PRODUCIBILITY FORECASTING IN DISH–STIRLING CONCENTRATED SOLAR POWER SYSTEMS

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Accurate prediction of energy producibility in Concentrated Solar Power (CSP) systems, and in particular Dish–Stirling configurations, represents a fundamental challenge due to the strong interdependence among optical, thermal, and environmental variables. These systems exhibit non-linear dynamics, rapid transients, and multivariate interactions that are difficult to capture through traditional statistical approaches. Advanced neural network models provide a powerful framework to address this complexity by learning latent relationships directly from experimental data.

This study compares two state-of-the-art architectures: a Graph Isomorphism Network (GIN) and an enhanced Graph Attention Network (GAT) optimized through evolutionary search. Both models transform the dataset into a graph in which each operating condition is represented as a node connected to its nearest neighbours, enabling the extraction of local structural patterns that classical machine learning methods cannot exploit. The GIN model emphasizes structural invariance and uniform message passing, ensuring stable feature aggregation across similar states. Conversely, the GAT model integrates attention mechanisms that weigh the relative importance of neighbouring nodes, allowing the network to focus selectively on the most influential operating conditions—an essential capability when dealing with variability in solar irradiance, thermal gradients, and wind-driven fluctuations.

The comparison highlights shared strengths, non-linearity handling, robustness to noisy measurements, and improved predictive accuracy, while underscoring their distinct roles: GIN offers reliable and consistent structural learning, whereas GAT provides adaptive, context-dependent feature extraction. Together, these results demonstrate the relevance of neural architectures, and especially graph-based models, for advancing CSP producibility forecasting and supporting more efficient plant operation and control strategies.

THERMAL CHARACTERIZATION AND PROTOTYPE TESTING OF GEOPOLYMER COMPOSITES FOR SENSIBLE HEAT STORAGE

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This work presents an integrated experimental framework aimed at developing and characterizing innovative geopolymer-based materials for medium-temperature sensible heat thermal energy storage (SHTES) and at validating their behaviour under realistic operating conditions. A comprehensive preliminary characterization campaign was conducted to assess the microstructural, mechanical, and thermophysical properties of different geopolymer formulations incorporating sand, waste glass powder, and carbon fibres at various concentrations. Techniques including SEM/EDS, optical microscopy, micro-CT, Heat Flow Meter analysis, Differential Scanning Calorimetry, and calorimetric testing were used to evaluate porosity, crystalline phases, thermal conductivity, and specific heat capacity. Results highlight the strong influence of aggregate type and fibre dispersion on thermal performance, identifying formulations with sand and low carbon-fibre content (≈0.5 wt%) as the most promising due to their balanced conductivity, heat capacity, and structural homogeneity. Building on these findings, a dedicated experimental prototype was designed and constructed to analyse transient heat transfer within geopolymer specimens under controlled thermal cycling. The system consists of an insulated thermohydraulic loop in which diathermic oil at 150 °C circulates through embedded tubing inside a geopolymer block instrumented with four internal thermocouples. Additional sensors measure inlet and outlet oil temperatures, tank temperature, pressure, and flow rate. A custom Python-based acquisition platform enables simultaneous high-frequency data logging and real-time monitoring of all variables, allowing reconstruction of internal temperature profiles and accurate estimation of thermophysical parameters during dynamic operation.

The integrated methodology, linking detailed material characterization with prototype-scale thermal testing, provides a robust basis for evaluating and optimizing geopolymer composites as sustainable, low-carbon alternatives to conventional TES materials. This approach supports future development of geopolymer-based SHTES units with improved efficiency, durability, and environmental performance.

Finanziato dall'Unione europea NextGenerationEU
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RAMAN SPECTROSCOPY CHARACTERIZATION OF COATING LAYERS IN GLASSES FOR BIPV APPLICATIONS

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Laminates for Building Integrated PhotoVoltaic (BIPV) are generally composed, from the external surface towards the internal one, by: front cover, front encapsulant, solar cell layer, rear encapsulant and rear cover [1]. In particular, the front cover is made by the bulk material, usually glass, with its both external and internal surfaces. The former plays an important role in BIPV modules, due to its functional tasks: to reduce solar radiation reflection by the external side, in order to increase energy conversion efficiency, and to provide the requested aesthetic appearance [2]. Commercial glasses used as the front cover of laminates for BIPV applications are often coated on one side with a layer of material with functional characteristics that enhance both system efficiency and aesthetics.
Inside a long lasting collaboration between the Dipartmento di Fisica e Chimica "Emilio Segré" (DiFC) of the Università di Palermo (UniPa) and the Institute for Renewable Energy, Eurac Research (Bolzano), several samples of coated glasses to fabricate laminates for BIPV applications were sent by Eurac to DiFC to perform several optical tests on them, in particular Raman spectroscopy, both on the coated side and on the uncoated one, to gain needed informations.
In this work, the investigation performed by Raman spectroscopy on the coating sides of above samples, including the specific analysis of the features detected by the optical microscope observation on the coating surfaces, are described, and the related results are reported and discussed.

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Finanziato dall'Unione europea NextGenerationEU
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INTEGRATION OF 2D MXENES WITH 3D PEROVSKITES FOR ENHANCED PHOTOVOLTAIC APPLICATIONS

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The integration of MXenes[1] with semiconductive materials such as perovskite (PVK) is emerging as a promising avenue for enhancing the performance of optoelectronic devices. This integration is particularly beneficial for applications such as photodiodes, where the synergy can result in enhanced responsivity. In this study, we investigate by theoretical simulations the band offsets of the integrated system consisting of PVK and MXene. Specifically, distinct PVK terminations have been analyzed for both PVK and MXene within the integrated system. For the former, terminations involving iodine and lead have been selected; conversely, for the latter, terminations mainly involving hydroxyl and chlorine have undergone examination. To attain a deeper understanding of the band offsets, the contributions of atoms and orbitals near the Fermi level have been disentangled. The results elucidate how the position and subsequent modulation of the Fermi level can be affected by the PVK termination. This leads to implications regarding charge extraction at the heterojunction and the consequent engineering of carrier separation and mobility within these integrated systems [2].

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2D SINGLE-CRYSTAL HYBRID PEROVSKITES: TOWARDS NEXT-GENERATION LEAD-FREE PEROVSKITE OPTOELECTRONICS

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Single-crystal hybrid perovskites (SC-HP) have emerged as leading candidates among next-generation semiconductors owing to their outstanding properties, including tunable bandgaps, high absorbtion coefficients, excellent photophysical properties, intense luminescence and their low-cost solution-based processability [1, 2]. Two-dimensional SC-HP are especially interesting as their long-range ordered multiple quantum well structure induces additional properties, including large excitonic effects. Compared to their polycrystalline counterparts, 2D single-crystal perovskites exhibit longer carrier lifetimes and diffusion lengths, lower trap state density, and enhanced environmental stability [3]. These materials have now positioned themselves as a new class of 2D materials beyond graphene and other van der Walls materials and have attracted significant interest for advanced device applications in photodetection, light generation, photonics, and neuromorphic computing, as well as for fundamental investigations into optoelectronic phenomena. In this poster, we report recent advancements in optoelectronic devices based on 2D thin films of PEA_2PbI_4 single crystals grown using the space-confined approach. Our results demonstrate the synthesis of high-quality single-crystalline materials with low defect densities and controllable bias-induced ion migration, providing deeper insights into the underlying photoresponse mechanisms [4]. Moreover, we discuss recent progress toward lead-free 2D single-crystal hybrid perovskites that aim to retain the remarkable optoelectronic properties of these materials while addressing environmental and toxicity concerns [5].

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WET SYNTHESIZED NANOSTRUCTURED MATERIALS FOR ENERGY APPLICATIONS

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The development of advanced nanostructured materials that combine unique size-dependent characteristics with versatile processing methods stands as a major frontier in nanotechnology and in the design of innovative materials for energy. Indeed, wet chemical approaches enable the production of nanomaterials with diverse morphologies, dimensions, and chemical compositions, offering adjustable chemical and physical characteristics. Inorganic semiconductor nanocrystals have found extensive use as sensitizers in solar cells, owing to their excellent quantum efficiency, chemical robustness, resistance to photobleaching, and spectral tunability across a broad wavelength range. More recently, perovskite nanoparticles have garnered significant interest for their exceptionally bright emission [1,2.3], while carbon dots have attracted attention as luminescent materials for solar converters, due to their interesting optical properties and their low toxicity [4,5]. Metal oxide nanoparticles including TiO_2, SnO_2 and WO_3 exhibit intriguing size- and shape-dependent characteristics, remarkable physicochemical adaptability, distinctive reactivity, and surface chemistry that prove valuable in fabricating transparent photoelectrodes for perovskite solar cells, as well as capacitive electrodes for battery and energy storage applications [6,7]. The optical transmittance and electrical conductance of nanostructured metal oxide films can be further enhanced through appropriate doping strategies. Furthermore, post-synthesis modification techniques permit the manipulation of these nano-objects—incorporating them into solid hosts, depositing or organizing them on substrates while maintaining their intrinsic properties and introducing novel collective functionalities [8]. This contribution will present solution-phase synthesis of nanomaterials via colloidal, solvothermal and precipitation methods, along with their morphological and physicochemical properties, in the context of photovoltaic and energy conversion applications.

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SUSTAINABLE AND SCALABLE SYNTHESIS OF NANOSTRUCTURED OXIDES FOR ENERGY CONVERSION AND STORAGE DEVICES: VALIDATING APPLICATION-RELEVANT PROPERTIES IN UPSCALED MANUFACTURING

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The transition toward a sustainable energy future requires reducing reliance on fossil fuels and developing efficient, low-impact technologies. Nanostructured materials are central to this shift, serving as functional components in photovoltaics, batteries, and electrochemical reactors. Their tunable properties—controlled through size, morphology, and composition—enable significant performance enhancements. However, converting laboratory-scale syntheses into scalable, reproducible, and cost-effective industrial processes remains a major challenge.

This work presents an eco-friendly aqueous-phase synthesis of SnO_2 nanostructures carried out at relatively low temperatures and designed for industrial scalability. Systematic optimization of precursor concentration, temperature, and reaction time enabled precise control over particle size, morphology, and crystallinity. The scalability and robustness of the process were demonstrated both at laboratory scale and in an industrially relevant environment. Extensive morphological, structural, and spectroscopic characterizations confirmed the reproducibility of the material properties across different scales, while electrochemical tests validated their suitability for practical energy applications. A dedicated Life Cycle Assessment (LCA) was performed to quantify and monitor the environmental impacts of the synthesis during scale-up, providing insight into resource use, energy consumption, and emissions. This analysis offers a framework for guiding process optimization and ensuring sustainability throughout upscaling. The overall technology readiness level of 4–5 indicates successful validation of the materials and synthesis route under relevant operational conditions. By demonstrating that a low-temperature aqueous synthesis can deliver both scalability and consistent material functionality, this study establishes a viable pathway toward the industrial production of nanostructured SnO_2.

The work, carried out within the "SPARKLE – Scalable Production of Advanced Nanostructures for Electrodes" (PNRR NEST – Network 4 Energy Sustainable Transition) project, represents a significant step toward integrating nanostructured materials into sustainable energy technologies.

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HIGH-TRANSPARENCY DIELECTRIC/METAL/DIELECTRIC ELECTRODES FOR EFFICIENT SEMI-TRANSPARENT PEROVSKITE SOLAR CELLS

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Semi-transparent perovskite solar cells (ST-PSCs) combine high energy efficiency with optical transparency, making them ideal for applications such as building-integrated photovoltaics (BIPV) and tandem devices. [1] Conventional metallic thin films, while conductive, often reduce device transparency. [2] To overcome this limitation, dielectric/metal/dielectric (D/M/D) multilayer electrodes have emerged as an effective approach to simultaneously achieve high optical transmittance and low electrical resistance. [3] The design of D/M/D electrodes is based on the physicochemical principles related to the modulation of the light absorption due to the surface plasmons of the metal, highly sensitive to the refractive index of the dielectric at the interface, and on the multiple light refractions within D/M/D the multilayer, which reduce optical losses. [4] This study investigates innovative D/M/D electrode architectures employing gold as the metallic layer, sandwiched between metal oxides layers to form the top anode in ST-PSCs. Both symmetric (D/M/D) and asymmetric (D_1/M/D_2) configurations were developed, by using molybdenum oxide (MoO_x) and tungsten oxide (WO_x) as dielectrics to evaluate optical and electrical performance. The multilayers MoO_x/Au/MoO_x, MoO_x/Au/MoO_x, and WO_x-based alternatives were deposited by thermal evaporation, a scalable and industry-compatible technique ensuring uniform and reproducible ultra-thin films. The multilayer was characterized by Secondary Ion Mass Spectrometry (SIMS) depth profiling, revealing well-defined, planar, and uniformly stacked layers with no evidence of intermixing or atoms diffusion. Then, the optical and electrical properties were characterized by UV-Vis-NIR spectroscopy and sheet resistance measurements, respectively. The results show that MoO_x/Au/MoO_x electrodes exhibit a well-balanced combination of optical transparency and conductivity, confirming their suitability for use as top electrodes in ST-PSCs. Au-based systems demonstrated slightly superior conductivity, without significant performance loss. Moreover, asymmetric D/M/D architectures, particularly those integrating WO_x, achieved higher average visible transmittance compared to symmetric structures, enhancing overall optical performance. These findings underline the potential of Au-based D/M/D multilayers as efficient and scalable electrodes for next-generation semi-transparent perovskite solar cells, paving the way for their integration in energy-harvesting windows and other transparent photovoltaic technologies.

Acknowledgements: This work has been developed in the framework of the project 'Network 4 Energy Sustainable Transition – NEST', code PE0000021, CUP B73C22001280006, Spoke 1, funded under the National Recovery and Resilience Plan (NRRP), Mission 4, by the European Union – NextGenerationEU.

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FAST-POLYMERIZING POLYSILOXANE COATINGS FOR ONE-STEP ENCAPSULATION OF SEMI-TRANSPARENT PEROVSKITE SOLAR CELLS

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The energy transition is a complex ongoing process focusing on the use of renewable sources of energy aiming to limit the global climate crisis. Solar energy is at the forefront of innovation, propelling the development of advanced materials for a wider application of photovoltaic (PV) devices. [1] In this context, perovskites thin films showed low cost, flexibility, and semitransparency, ideal for many applications not accessible to silicon-based technology, such as PV windows and tandem devices. [2-3] Nevertheless, the widespread adoption of perovskites is hindered by their instability under ambient humidity and oxygen levels. Encapsulating coatings can shield PV devices from environmental chemicals, thus enhancing their long-term stability towards widespread commercialization. [4] However, the encapsulation process can represent a critical step itself because of the relatively high processing temperature or long curing times the device undergoes. In this work, a novel fast-polymerizing polysiloxane coating is developed as a protective layer for semi-transparent perovskite solar cells (ST-PSCs). The new formulation containing polymethylhydrosiloxane (PMHS) and hydroxy-terminated polydimethylsiloxane (PDMS-OH) can be directly casted on the ST-PSCs and polymerized in 10 min at 80 °C through dehydrosilylation reaction. [5] Such experimental conditions are successful for the ST-PSCs encapsulation maintaining their electrical and optical performances. Further improvements in the protective features of the polysiloxane encapsulating layer were explored by introducing the crosslinking agent trymethoxymethylsilane (TMMS). Experimental results show that this encapsulation process is compatible with the tested devices, while aging studies at 85 % relative humidity (RH) exhibit a slight initial decrease in PCE during the first hour of exposure, followed by a stabilization phase over time. These results confirm a successful encapsulation process for ST-PSCs, and suggest developments for the encapsulating polymers herein proposed can represent an effective and affordable class of polysiloxanes for the encapsulation of thermal sensitive ST-PSCs towards a longer durability of such devices.

Acknowledgements: This work has been developed in the framework of the project 'Network 4 Energy Sustainable Transition – NEST', code PE0000021, CUP B73C22001280006, Spoke 1, funded under the National Recovery and Resilience Plan (NRRP), Mission 4, by the European Union – NextGenerationEU.

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PROTEIN SELF-ASSEMBLY FOR THE DESIGN OF TUNABLE GOLD NANOPARTICLES IN HYBRID BIOMATERIALS

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Amyloid fibrils have recently emerged as versatile biomaterials in nanotechnology, photovoltaics and sensing due to their mechanical stability, chemical resistance, and ability to self-assemble into highly ordered structures [1,2]. Among their various applications, their use as bio-templates for the synthesis of metallic nanoparticles has attracted significant attention, offering a green and tunable approach for the production of hybrid materials [3].

In a previous study, we developed a simple method for producing hen egg white lysozyme (HEWL) amyloid fibrils decorated with gold nanoparticles (AuNPs), under high temperature and acid pH, which facilitates the interaction between protein and gold ions. We found that, during the fibrillation process, the reactive oligomeric intermediates act as intrinsic reducing agents, enabling the in situ synthesis of AuNPs, with an average size of 4 nm, regularly spaced at distance of about 100 nm along the HEWL amyloid fibrils [4].

Here, we analyse the molecular mechanisms underlying the bio-mediated synthesis of AuNPs using spectroscopy and microscopy methods, with particular focus on the early stages of protein aggregation, aiming at the rational control of the physicochemical properties of the material.

In perspective these studies may lead to a tunable and sustainable synthesis strategy offering a straightforward route to design hybrid AuNP–protein fibril systems with controllable structural and optical characteristics, presenting promising opportunities for applications such as photovoltaics and biosensing.

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ADVANCING BIPV: SHINGLED HJT TECHNOLOGY FOR HIGH-EFFICIENCY AND AESTHETIC SOLAR INTEGRATION

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This work presents the development, characterization, and preliminary evaluation of innovative Building-Integrated Photovoltaic (BIPV) modules based on shingled Heterojunction (HJT) solar cell technology. The aim is to combine high electrical efficiency with architectural aesthetics, addressing a key requirement for PV integration in building envelopes. Twelve prototypes were fabricated using HJT cells arranged in shingled strings, designed to operate at high voltage and low current to minimize resistive losses and boost power density. Multiple Bills of Materials (BoMs) were tested, including Glass-Glass and Glass-Backsheet configurations, with various combinations of colored glasses and Backsheet. These configurations were selected to maximize appearance uniformity, enabling seamless integration into building surfaces. Indoor characterization included standard-condition I-V measurements using a Pasan A+A+A simulator and electroluminescence (EL) imaging before and after lamination, together with colorimetry tests.
Flash tests were conducted to determine electrical characteristics, while EL analysis assessed structural integrity, identifying microcracks and validating the positive effects of optimized lamination. The research aims to extend to accelerated tests performance monitoring, bridging the gap between laboratory fabrication and real-world deployment. Humidity freezing tests were performed in a climatic chamber. This study provides a comprehensive methodology, from material selection and optimized lamination to controlled indoor testing. By systematically investigating both aesthetic and functional aspects, it offers critical insights into the adoption of shingled HJT technology in the rapidly evolving BIPV sector.

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THERMOGRAVIMETRIC STUDY ON THE IMPACT OF $ZnCl_2$ BASED HEAT TRANSFER FLUIDS ON THE PYROLYSIS PROCESS OF PLASTIC WASTE

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Over the years, the worldwide production of polymers has risen sharply, reflecting the growing demand for plastics in many sectors such as packaging, construction, transportation, and healthcare. Zinc chloride ($ZnCl_2$) has been proposed as a high-temperature heat-transfer fluid (HTF) for concentrated solar thermal power (CSP) technology [1]. Thermochemical carbonization using zinc chloride also offers an alternative route [2] to convert waste carbonaceous materials into valuable carbon-rich solids such as biochar, while simultaneously producing molecular hydrogen and hydrogen-rich gaseous products.

The influence of $ZnCl_2$ as a catalyst on the thermal decomposition of single-use plastics such as high-density polyethylene (HDPE), isotactic polypropylene (iPP), and polyethylene terephthalate (PET) was examined using a thermogravimetric analyzer (TGA) under non-isothermal conditions with controlled heating rates. For HDPE and iPP, the addition of $ZnCl_2$ to the polymer at a loading of 35 ± 10 wt% resulted in a significant decrease in the apparent activation energy of the devolatilization steps. In contrast, for PET, the presence of $ZnCl_2$ modified the reaction pathway, as evidenced by the appearance of new mass-loss peaks at temperature ranges distinct from the single peak observed for pure PET. The collected results indicate that molten $ZnCl_2$ serves as an efficient and adaptable catalyst for the pyrolysis of single-use plastics.

Acknowledgement**:** this work was developed under the Project code PE0000021, Concession Decree No. 1561 of 11.10.2022 adopted by Ministero dell'Università e della Ricerca (MUR), CUP B73C22001280006 , Project title "Network 4 Energy Sustainable Transition – NEST"**.**

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ELECTRODEPOSITION OF ZINC-COPPER FOAM ELECTRODES FOR CO_2 ELECTROREDUCTION

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A competitive technology to reduce carbon dioxide emissions and store energy from renewable sources is the electro-reduction of carbon dioxide (ERC). In this process, a catalytic electrode is used to convert CO_2 into fuels and chemicals (e.g. carbon monoxide, formic acid, methanol) [1] within an electrochemical cell. Noble metals (e.g., silver) can ensure satisfactory selectivity (up to >90%) towards CO but are expensive [2]. Compared to noble metals, zinc can ensure comparable selectivity towards CO, but it has lower activity (i.e., reduced current density at prescribed potential). This limitation can be mitigated by increasing the electrode specific surface area and/or by the introduction of copper. In this contribution, the synthesis of porous zinc-copper electrodes by bubbling electrodeposition is presented [3]. The reported experimental study is aimed at evaluating how electrodeposition parameters influence foam structure, morphology and composition, which dictate the catalytic activity. The impact of electrodeposition parameters (current density, charge transfer, Zn/Cu ratio in the bath) on the morphology, structure, and amount of deposited zinc is analyzed through SEM, XRD and AAS analyses. The electrocatalytic performances of the fabricated electrodes are described by analyzing the results of catalytic tests conducted in an H-type cell under potentiostatic conditions at different potentials (-1.5, -1.7, -1.9 V vs. Ag/AgCl). The research elucidates the impact of copper content and electrodeposition charge on morphology and structure, providing guidance for the optimal synthesis of zinc–copper foams for ERC.

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A TOOL FOR SOLAR TECHNOLOGIES ECO-DESIGN FOR ADVANCED NEST OPTIONS

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Solar energy will make a significant contribution to the global energy supply in the near future as well as in the long-term, which suggests the introduction of innovative technologies. Eco-design is encouraged to apply at the early stage of the technology development so that these innovative solar technologies could be developed with the largest energy and environmental benefits. In order to support the eco-design of solar technologies of the Network for Energy Sustainable Transition (NEST) project, an excel based eco-design supporting tool, named Solar Technologies Eco-design for Advanced NEST Options (STEFANO) has been developed. It provides engineers, designers, and other stakeholders with the general guidelines for solar technologies, and specific measures for NEST technologies such as perovskite solar cells, organic solar cells, concentrating solar power, tandem solar cell, building integrated photovoltaics based on perovskite, and some electronic subsystems. Besides, the tool allows users to compare the "eco-design points" of the technologies that are under the eco-design process and the reference technology, based on life cycle assessment (LCA) and life cycle costing. In case your eco-designed technologies have higher efficiency, it is possible to input the actual efficiency and compare the eco-design points. STEFANO is a quick review tool of eco-design guidelines and measures for solar technologies. It is easy to use (e.g. does not need expertise) and easy to access (e.g. excel can be accessible for all users). The tool works with built-in datasets, reducing the need for input data. Although STEFANO does not provide the detail and comprehensive information as an LCA software, it is potential to integrate the LCA software into this tool for the full assessment and detail eco-design measures.

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SEMI-TRANSPARENT C-Si PV MODULES FOR DIFFUSIVE & TRANSPARENT AGRIVOLTAICS: FROM PROTOTYPING TO OUTDOOR TESTING

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Agrivoltaics (Agri-PV) represents a promising solution to improve land-use efficiency by simultaneously allowing crop growth and photovoltaic (PV) energy generation, with additional benefits for crop production if properly engineered. However, when crystalline silicon (c-Si) PV modules are used for Agri-PV, even in semi-transparent configurations, shading occurs over crops, potentially reducing agricultural yields. Enhancing light diffusion could be a key strategy to partially compensate for this effect, as diffuse light is more efficiently utilized by most plants. In a previous study (Memminger, Minini et al., submitted to PIP, 2025), through the testing of several stacks and mini-modules, it was demonstrated that the transparent section of an Agri-PV module can be engineered to enhance light diffusion without significantly compromising the energy output.

In this framework, it is important to understand how PV modules light transmittance and scattering behavior, expressed as relative Angle-resolved scattering (ARSR) function, affect plants' growth. To this end, among the optically analyzed combinations, three were selected to realize large-scale Agri-PV modules, so that two distinct pairs could be identified: one pair featured nearly identical Global Total Transmittance (~ 85%) but differed markedly in ARSR (~46% vs ~4%), while the other pair exhibited similar ARSR (~46 and 42%), but differed substantially in transmittance (~86% vs ~67%). The aim was to decouple the impact of these two variables, assessing separately their effect on crops growth. Moreover, to isolate the impact of cell coverage, the same modules designs were fabricated without cells. These modules were then installed on six Agri-PV greenhouse units, one of which was left open and served as a reference. Inside each greenhouse four pots were positioned and planted with salad in both green and purple varieties, as well as red radish, analyzing their growth over a six-week period in early autumn. Alongside continuous monitoring of salad leaf expansion, chlorophyll content and photochemical efficiency measurements were performed on all crops. Preliminary results indicated that all enclosed greenhouses outperformed the open reference, with the chlorophyll content being higher for purple salad under the diffusive modules, while for green salad transmittance appeared to play a more prominent role. Additional statistical analysis will be required to strengthen the conclusions; accordingly, the next phase of the study will involve expanding both the greenhouse setup and the number of crop species evaluated.

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GREEN NANOMATERIAL SYNTHESIS VIA RF SPUTTERING IN LIQUIDS AND ONTO POWDERS FOR SCALABLE, CRM-FREE CATALYSTS FOR WATER ELECTROLYSIS

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We present a dry and green synthesis approach using RF magnetron sputtering, a physical vapor deposition (PVD) technique, to fabricate nanofluids (nanoparticles suspended in liquids) and nanohybrids (catalyst-coated powders) as catalysts for water electrolysis applications. This solvent-free method eliminates hazardous chemicals and complex multi-step procedures, enabling sustainable and scalable production of ultrapure catalysts. For nanohybrids, copper-coated multi-walled carbon nanotubes (Cu/CNTs) and nickel-coated titania nanopowders (Ni/TiO_2) were synthesized via RF magnetron sputtering combined with a vibrating deposition stage, which ensured uniform nanoparticle coating.[1] For nanofluids, ultrapure nanoparticles (gold, copper, nickel, platinum) were obtained by RF sputtering directly into a liquid medium, preserving their native nanoscale morphology.[2] These nanoparticles were then seamlessly transferred onto functional substrates such as Nafion membranes and graphene, forming uniform catalyst-coated membranes (CCM) and nanohybrids with ultra-low precious metal loading at the nanogram scale. Comprehensive characterization using SEM-EDX, XPS, XRD, AFM, and TEM confirmed nanoparticle integrity and dispersion. Electrochemical tests demonstrated an excellent hydrogen evolution reaction (HER) performance, comparable to commercial Pt-based materials. Therefore, this process addresses key challenges in PEM electrolyzer technology by lowering material costs, and offering a green, scalable, and industrially viable fabrication route.

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PVD COATINGS APPLIED TO HYDROGEN TECHNOLOGY

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The importance and the use of hydrogen as energy carrier is continuously growing and the development of a suitable infrastructure for its transport and storage is necessary. However, both transportation and production can encounter issues.

Considering the production processes, up to now large part of the hydrogen is produced by reforming and this processes provide gas mixtures with high content of by-products (CO, CO_2, H_2S etc.) that require proper purification steps, for example through the use of metallic membranes that can be produced trough thin film deposition over porous substrates.

Considering the problems of transportation, steels, the most important materials in the engineering applications, are susceptible to hydrogen embrittlement, which promote hydrogen-assisted cracking and eventually result in a significant loss of ductility and degradation of mechanical properties. Hydrogen permeation barriers are possible solutions to mitigate the deleterious effects of hydrogen on steels. They are protective coatings composed by materials with low intrinsic hydrogen diffusivity and solubility, that can reduce or delay hydrogen ingress into the substrate.

PVD technology seems one of the most promising to obtain both the type of coatings thanks to the high purity and density of deposited film and the low process temperature. Considering membranes, Pd-based alloys are generally employed, with the use also of other elements, generally transition metals, in order to reduce palladium content. [1] In barrier layer applications instead, oxides, carbides and nitrides are generally the most commonly employed coatings, with the nitrides that showed the most lower permeabilities in the order of 10^{-18} mol/s/m/√Pa. [2] Also the microstructure of the coatings can significantly influence the hydrogen permeability, in particular the presence of numerous interfaces can inhibit the formation of fast diffusion channels of hydrogen and can reduce the diffusivity of hydrogen in the coatings. [3]

High Power Impulse Magnetron Sputtering (HiPIMS) PVD technique was employed in this study to deposit NbVPd alloys on porous alumina for membrane application or nitrides-based coating on ARMCO steel as hydrogen barriers. The obtained coatings were characterized through SEM and XRD characterization and the functional properties evaluated in contact with hydrogen trough permeation tests or with electrochemical techniques.

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USING FLUORESCENT INORGANIC NANOPARTICLES AS SOLAR SHAPERS TO IMPROVE THE EFFICIENCY OF PHOTOSYNTHESIS

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Carbon emission is one of the biggest crises of modern times. Extensive research are devoted to engineering pathways toward carbon neutrality. Plants fix approximately 120 billion tons of carbon each year through photosynthesis, a natural process that utilizes solar spectrum as the sole source of energy. The photosynthetically active region ranges from 400 nm to 700 nm, representing only 40% of the integrated solar spectrum. Increasing the efficiency of photosynthetic organisms can accelerate our path to carbon neutrality by enhancing crop production. [1] However, fulfilling this goal requires a physical mechanism to convert light from an undesirable wavelength (ultraviolet or infrared) to a more desirable one, such as fluorescence. Increasing the intensity of visible light around 700 nm represents a valuable strategy to increase the efficiency of photosynthesis. Here, we use semiconductor nanocrystals (NCs) to enhance the photosynthetic efficiency by converting light from a photosynthetically inactive region (ultraviolet) to a photosynthetically active region (visible). We choose copper indium disulfide (CIS) nanocrystals, a direct band-gap semiconductor with a band-gap of 1.45 eV in the bulk and a Bohr exciton radius of 4.1 nm. [2] We exploited the size dependent emission of CIS to synthesize a core with emission wavelength of 700 nm. The inherent low quantum yield of these NCs arises from the surface defects we tackled it by introducing a non-toxic shell of zinc sulfide (ZS) around the CIS core which passivated the surface thereby enhancing the quantum yield to 7 times of the final core/shell NCs. We engineered a synthetic methodology to grow thick shells over the CIS core to obtain a high quality CIS/ZS core/shell that performs as solar shapers. We incorporated these NCs with polymer to make solar shaper films which are used to study the algae growth. This non-toxic NCs shows potential in enhancing the visible light availability for photosynthesis and thereby leading to improved carbon fixing and higher crop yields.

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PULSED LASER MELTING FOR TOPCON TECHNOLOGY: NEW ROUTES TO HIGHER EFFICIENCY

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Tunnel oxide passivating contacts (TOPCon) are a leading route to high-efficiency crystalline-silicon (c-Si) solar cells. The core structure poly-Si/SiO_x/c-Si uses an ultrathin (<2 nm) tunnel oxide to passivate the c-Si surface while a heavily doped poly-Si layer provides carrier selectivity. Carrier transport is dominated by tunneling through the SiO_x layer, although direct conduction through local oxide openings ("pinholes") in textured contacts can also contribute. In this work we investigate both pathways and show how pulsed laser melting (PLM) can be used to enhance performance without sacrificing passivation.

Using nanosecond-PLM, we achieve hyperdoping of poly-Si with boron and gallium beyond their equilibrium solid-solubility limits, yielding low-resistivity contacts while preserving the SiO_x/c-Si interface. The surface-localized heating inherent to PLM suppresses boron diffusion through SiO_x that typically degrades passivation in conventional processes [1,2]. Thermal-stability assessments further support the robustness of the laser-treated stacks and their suitability for industrial integration.

For the pinhole-mediated pathway, we explore PLM as a method to create nanoscale openings at the tips of pyramidal-textured cells while maintaining passivated contacts on the pyramid facets [3]. Atomic force microscopy (AFM) tracks morphology as a function of laser parameters, and conductive AFM (c-AFM) provides spatially resolved current maps that clarify carrier transport through individual pinholes [3,4].

Overall, PLM enables hyperdoped, low-resistance poly-Si contacts with preserved passivation and controlled pinhole formation compatible with textured surfaces, together outlining a viable route to TOPCon performance gains with manufacturable process windows.

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STABILITY UNDER ILLUMINATION OF SEMI-TRANSPARENT $FAPbBr_3$ PEROVSKITE MINI-MODULES

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We present the results of a reliability study conducted on semi-transparent/bifacial $FAPbBr_3$ perovskite mini-modules. Stability under illumination was probed in indoor conditions at 1 sun irradiance with a white LED array illuminator for a series of 40 ks experiments, each followed with a 40 ks recovery monitoring phase. The DUTs were tested under different operating conditions: MPPT (Maximum Power Point Tracking), OC (open-circuit) and SC (short-circuit); conversely, recovery was monitored only in the dark in open-circuit conditions.
In OC conditions, a slight degradation of the DUT is observed, mainly relating to a decrease in V_{oc} and in shunt resistance, with a subsequent decrease in all other related parameters; the reversibility of such degradation is uncertain. In OC conditions, current does not flow, but the DUT voltage is maximized, which may cause ion drift and accumulation towards the interfaces, potentially leading to irreversible reactions.
In SC conditions, a more drastic degradation of the DUT is observed, mainly relating to the potential failure onset of one or more single cells of the mini-module due to high current throughput, leading to a significant decrease in fill-factor and a slight decrease in I_{sc} (while V_{oc} remains relatively stable). In SC conditions, current flow is maximized, but the DUT voltage is neutralized, so the observed degradation may derive from current-induced phenomena affecting the charge-transport and/or contact layers/interfaces.
In MPPT conditions, a clear degradation of the DUT is observed, mainly relating to a progressive fill-factor reduction, seemingly stemming from a combined reduction of I_{sc}, V_{oc}, R_{sh}. As MPP conditions entail both a relatively high voltage and current, the results obtained in such conditions seemingly fit well between those of the OC and SC conditions, and the observed degradation may derive from a multitude of factors pertaining both to current flow and DUT voltage.

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EPR SPECTROSCOPY APPLIED ON PEROVSKITE SOLAR CELLS MATERIALS

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Many species in the bulk and interface layers of Perovskite solar cells (PSC) such as impurities or crystal defects, can be responsible for charge recombination in the cells. Understanding and characterizing these species and their roles is crucial because of their influence on the performance, efficiency, and stability of solar cells.
This study aimed at the investigation of a series of newly synthesized materials that could serve as Hole Transport Layers (HTL) in PSC. Organic molecules such as carbazole-based self-assembled monolayers (SAMs), arylamine-based dyes (TPA), and organic mixed-valence compounds (MVs), as well as different reduced graphene oxide poly-3-hexylthiohene blends (rGO@P3HT) have been analyzed using Electron Paramagnetic Resonance (EPR) Spectroscopy, a non-conventional method for solar cell materials characterization, that offers a unique insight by not only identifying interesting species but also examining photoexcitation and electron transfer processes at the molecular level.[1][2]
These materials have been studied in combination with various 3D perovskites ($MAPbI_3$ and $MAPbBr_{1,5}I_{1,5}$) and Electron Transport Layers (ETL) to create multimaterial thin film samples with HTL/ETL and HTL/perovskite/ETL architectures. These samples are studied by EPR spectroscopy to characterize the paramagnetic species generated at the interfaces of the different layers and to investigate the phenomenon of electron transfer toward the ETL.
The characterization of these compounds and thin film samples is carried out both in dark condition and under illumination, to discriminate stable and photogenerated species and to assess their persistence in environments mimicking the complex architectures of PSC.

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Questo libro di abstract è stato realizzato con il finanziamento dell'Unione europea – Next Generation EU

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