European Innovation Council

THE FUTURE OF **SOLAR-TO-X**

Harnessing renewables for a sustainable future

INDEX

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PREFACE

In our shift towards a sustainable future, rethinking the production of materials, chemicals and fuels is essential. Renewable resources – such as energy, water, and abundant molecules like carbon dioxide – offer significant potential to transform the global chemical and manufacturing sectors. The European Innovation Council (EIC) is committed to this transformative path, supporting it through various funding initiatives. Currently, two EIC Pathfinder Challenge portfolios are focused on sustainable hydrogen production[1] and CO_2/N_2 valorization,[2] featuring a total of 17 projects with a combined funding of EUR 58 million. Additionally, the EUR 24 million EIC Pathfinder "Solar-to-X" challenge is currently accepting applications for projects focused on transforming solar energy into other forms of sustainable energy or chemicals. The challenge emphasizes high-risk, visionary research with the potential for groundbreaking outcomes. The deadline for submission is 16 October 2024.[3]

Funding alone isn't enough; a robust solar fuels innovation ecosystem is crucial for accelerating progress. To address this, the EIC hosted a two-day Solar-to-X Innovation event on 4-5 June 2024. Over 130 delegates, including academics, start-ups, industry leaders, policymakers and investors from Europe and the US, gathered to discuss advancements from cutting-edge research to market-ready technologies. The event featured talks, panels, pitches and open discussions on the full spectrum of innovation—from academic breakthroughs to technology scaling and integration into existing energy systems. It represented a unique occasion to spark conversations and catalyze ideas around the future role of CCU, Power-to-X, and Solar-to-X technologies in the European energy system. This report provides a summary of the event's sessions and key outcomes, offering insights into the current state of the field and ways to foster technology transfer and innovation.

Carina Faber
EIC Programme Manager
for renewable energy conversion and alternative resource exploitation

[1] https://eichydrogen.eu/
[2] https://eic.co2nitrogen.eu/
[3] For details of the call, please see: https://bit.ly/4dcvLyn

ABOUT THE EVENT

On 4 and 5 June 2024, the EIC organized an event in Genk, Belgium, titled "Harnessing Renewables for a Sustainable Future." The event was held in collaboration with EnergyVille —which also kindly hosted the sessions— imec, the EuroTech Universities Alliance, SUNERGY, and several EU-funded projects, including CATART, CO_2NDOR, FlowPhotoChem, and SUNER-C.

Attended by over 130 people, the event:

- Provided a comprehensive overview of the current state-of-the-art in technologies such as Solar-to-X, Power-to-X, and CCU.
- Included pitches from key projects, which presented innovative results in the field of sustainability.
- Created an ideal environment for the exchange of ideas between top academics, visionary entrepreneurs, industrial leaders, policymakers, and investors.
- Devised plans to foster technology transfer and move from low Technology Readiness Levels (TRLs) to manufacturing and commercialization.
- Explored the development of a holistic methodology that combines cutting-edge technology with sustainable solutions.
- Catalyzed connections between partners and decision-makers for future projects.

The event helped align the realities of research and innovation with industrial and societal needs, bridging the gap between laboratory experiments and the European market. Overall, it provided a clear understanding of the impact that Solar-to-X — and other technologies for harvesting renewable resources — will have on sustainability, as well as their potential to promote a circular economy and defossilization. **Together with this report, the EIC aims to inform and guide policymakers and decision-makers across Europe, highlighting the achievements of researchers and accelerating the commercialization of early-stage discoveries.**

In addition to a diverse lineup of speakers, the program included panel discussions, participatory Q&A sessions, and parallel "focus sessions" to catalyze conversations between participants and key decision-makers from industry, policy and investment.

"It is rare to have the chance to participate in an event where the global vision, the technical and scientific aspects and the business approaches are coexisting in such a harmonious way. The contents have been made accessible to a public with a very broad background, but always without compromising on the rigor of the contents provided. The programme was ambitious and the organization exceptional."

- **Ennio Capria**, Business Developer at ESRF

"This vision to create an active community to tackle the Power-to-X challenge is really and sincerely inspiring. And some of keynote speakers are fascinating. I also appreciate [...] the opportunity to participate and contribute to this ecosystem, it is a way to bring our competences to the community and identify right partners towards building our consortium."

- **Lionel Ventelon**, COO at H2WIN

"Thanks for putting together this very nice line up of speakers, covering such a wide range of interesting views."

- **Antoni Llobet**, Group Leader at ICIQ

1. THE EUROPEAN INNOVATION COUNCIL (EIC) AND ITS SOLAR-TO-X STRATEGY

1.1 From scientific curiosity to innovation

by Carina Faber, European Innovation Council

This first presentation highlighted the transformative potential of Solar-to-X technologies in shaping future energy systems and addressing climate neutrality. Solar-to-X or artificial photosynthesis technologies enable the direct conversion of solar energy into fuels and chemicals, presenting a decentralized, sustainable alternative for long-term energy solutions and materials production. However, significant challenges remain, including technological, economic, and regulatory barriers that impede the path to commercialization. Given the high efficiency and cost-effectiveness of fossil-based processes, renewable alternatives require substantial regulatory and financial support to compete.

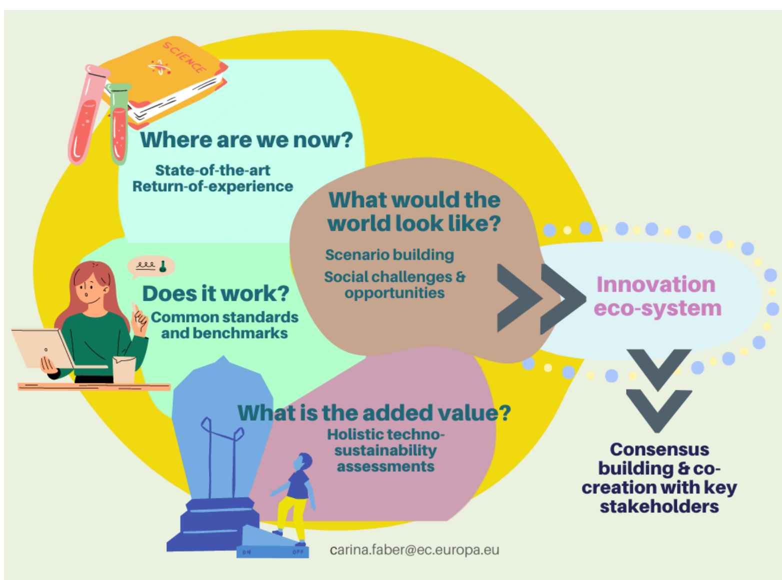
The overarching goal of the European Innovation Council (EIC) is to move Solar-to-X from the realm of scientific curiosity into practical technological innovation, creating solutions that meet societal needs. Solar-to-X technologies are part of a broader array of strategies that contribute to climate neutrality, including the electrification of society through renewable energy sources and the circular production of renewable fuels and chemicals. Unlike biomass-based processes, these fuels and chemicals are derived from renewable energy, water, and simple molecules like CO_2, offering diverse applications ranging from hydrogen production to sustainable aviation fuels and even proteins for food and feed.

The EIC has a strategic focus on supporting relatively mature technologies such as e-fuels and power-to-X while also backing breakthrough innovations at the fundamental research level, inspired by natural photosynthesis. It supports projects across the entire renewable fuels and chemicals value chain, from carbon capture and conversion technologies like electrolyzers to utilization technologies such as renewable gas fuel cells. This integrated approach ensures that each technology is optimized in relation to others, addressing key factors like the purity of CO_2 required by various conversion technologies.

The EIC aims to accelerate commercialization by fostering collaboration across projects at different maturity levels, connecting fundamental research with small and medium-sized enterprises (SMEs). This holistic approach ensures that innovation flows smoothly from research to market, paving the way for business models that can sustain these technologies.

A central theme of the presentation was the importance of understanding Solar-to-X's future role in energy systems. The EIC uses a variety of tools to support the development of Solar-to-X technologies. One key initiative is the SUNERGY roadmap, which coordinates efforts at the EU level to map out the steps needed to bring solar fuels and chemicals to market. Additionally, the EIC is developing a comprehensive techno-sustainability assessment methodology in collaboration with experts like Miet Van Dael from VITO. This framework assesses environmental, economic, and social impacts to guide both researchers and decision-makers in understanding the sustainability potential of solar fuel innovations. It ensures that emerging technologies are evaluated systematically, providing a transparent basis for comparing their performance and societal benefits.

The presentation also emphasized the importance of learning from existing projects, such as those involved in the EIC Horizon Prize, where finalists demonstrated the feasibility of producing methane and syngas under real-life conditions. Such experiences help shape future funding and innovation programs by providing real-world data on the challenges and successes of these technologies.



Looking ahead, the EIC's Pathfinder Challenge for 2024 focuses on developing decentralized Solar-to-X devices capable of converting solar energy into renewable fuels, chemicals, or materials. These projects are expected to collaborate on common milestones, enhancing device development, establishing shared standards, and advancing the underlying mechanisms that drive innovation in this field.

The event underscored the importance of fostering an inclusive innovation ecosystem that brings together policymakers, investors, academia, engineers, and industry representatives. A key takeaway was the need for clear communication across these sectors, with tools like the techno-sustainability assessment and Market Readiness Level (MRL) framework playing a vital role in bridging the gap between scientific research and business development. The EIC aims to optimize every stage of the renewable fuels and chemicals value chain, ensuring that early-stage research integrates seamlessly with broader efforts to create viable business models for the future.

In conclusion, the presentation highlighted the EIC's commitment to advancing Solar-to-X technologies by building a robust, interconnected innovation ecosystem that spans the entire value chain. This comprehensive approach is essential for developing sustainable, decentralized energy systems that will help mitigate climate change and transform the global energy landscape.

1.2 EIC's proactive management approach

Anne-Marie Sassen, European Innovation Council

European research institutions are excellent in conducting research, however, they tend to lose momentum when it comes to transforming research results into innovations and market opportunities. This is why EIC has a team of sector experts with a track record in science, technology transfer, and innovation strategy and management, the Programme Managers. They are appointed for a period of four years.

Programme managers are expected to boost the impact of EIC funding by fostering a pro-active management culture. They have the task of nurturing Pathfinder portfolios by developing together with beneficiaries a common vision and a common strategic approach that leads to a critical mass of effort. This involves the enhancement of new, recently developed fields of research, and the building-up and structuring of new communities, with the objective of bringing cutting-edge breakthrough ideas into genuine and mature market-creating innovations.

EIC Programme Manager Priorities

The “Harnessing Renewables for a Sustainable Future” event, developed by the EIC Programme Manager Carina Faber, is an example of how the portfolio approach already starts at the stage where the call for proposals is still open. It allowed potential applicants and other stakeholders in this domain to meet and discuss the real challenges that need to be met to develop solutions with market potential.

2. SOCIETAL CHALLENGES MEET DEEP-TECH SOLUTIONS

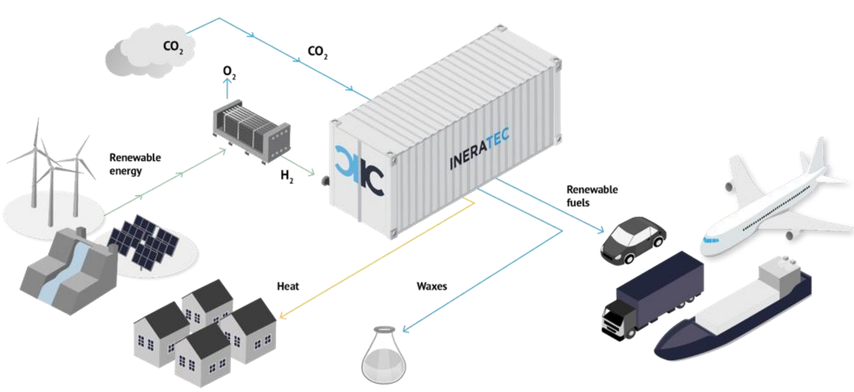
Europe is committed to becoming the first climate-neutral continent, which requires strong collaboration between policymakers and innovators to foster deep-tech solutions that address pressing societal challenges. This session featured four key decision-makers who were presented with pitches from projects, start-ups, and industry leaders showcasing innovations aimed at decarbonizing the European economy by 2050. The panel included Philippe Schild (DG RTD, European Commission), Vera Grimm (German Ministry for Research and Education), Fabien Ramos (DG Climate Action, European Commission), and Minerva Elías (European Investment Bank).

All panelists emphasized the importance of collaboration in driving creative thinking and innovative solutions. Grimm noted that "out-of-the-box ideas" could accelerate the growth of the Solar-to-X field, which is still relatively small compared to more established technologies. Elías explained how the European Investment Bank (EIB) can help speed up the journey from technology to market. She also introduced—exclusively at the Solar-to-X event—a new joint initiative between the EIB and the European Innovation Council (EIC), called the "Executives-in-Residence" program. This program will connect EIC grantees with experienced global leaders, offering mentorship and guidance to help create stronger business models and connect with clients, investors, and potential partners.

Ramos stressed the need for a comprehensive approach to reducing carbon emissions in Europe. "We need three pillars to achieve climate neutrality: reducing emissions, removing excess carbon dioxide from the atmosphere, and capturing it for utilization," he explained. He emphasized that the infrastructure to capture, transport, and convert CO_2 into value-added chemical products is essential for the continent's transition to a cleaner energy system. He also highlighted the need to view carbon dioxide as a resource to reduce dependence on fossil fuels, with technologies like Solar-to-X, Power-to-X, and Carbon Capture and Utilization (CCU) playing a central role.

Before the pitches began, Schild discussed the importance of climate resilience. He emphasized that while the transition to sustainable solutions must aim for climate neutrality, it must also prepare for the realities of the current climate crisis. Solutions must not only reduce current emissions but also withstand the challenges and changes brought about by a warming planet.

- **Hannah Johnson** (SunToX and Toyota Europe). The **European SunToX project** (October 1, 2020, to September 30, 2024) focused on innovative approaches to sustainable hydrogen production and storage. Specifically, the project explored the design of **photo-electrochemical devices** capable of producing **green hydrogen** directly from atmospheric humidity and sunlight. This method represents a significant step toward harnessing renewable energy sources for clean hydrogen production. In addition to hydrogen production, SunToX investigated the use of **silicon-based carriers** for the temporary storage of hydrogen. These carriers offer a carbon-free, energy-dense solution for hydrogen storage. Beyond serving as a liquid fuel, silicon-based carriers also present a promising option as a reducing agent in various chemical processes, including **plastic recycling**. This dual functionality supports both sustainable energy storage and advancements in recycling technologies, contributing to a circular economy.
- **Phillip Engelkamp** (Ineratec). This German start-up specializes in developing **modular chemical reactors** designed to produce **sustainable fuels and chemicals**. Their innovative technology includes the production of **synthetic aviation fuel** from water and CO_2. Ineratec has received funding from the European Innovation Council (EIC) and has successfully raised €129 million in private capital. This funding supports the development and distribution of their all-in-one **Power-to-X technology**, which is already operational in a 1 MW industrial plant. Ineratec's technology is set to benefit notable companies such as Swiss Air, Lufthansa, and Ferrostaal. Additionally, Ineratec is working on producing **value-added chemical products** such as methanol and waxes, further expanding their impact on sustainable chemical production.



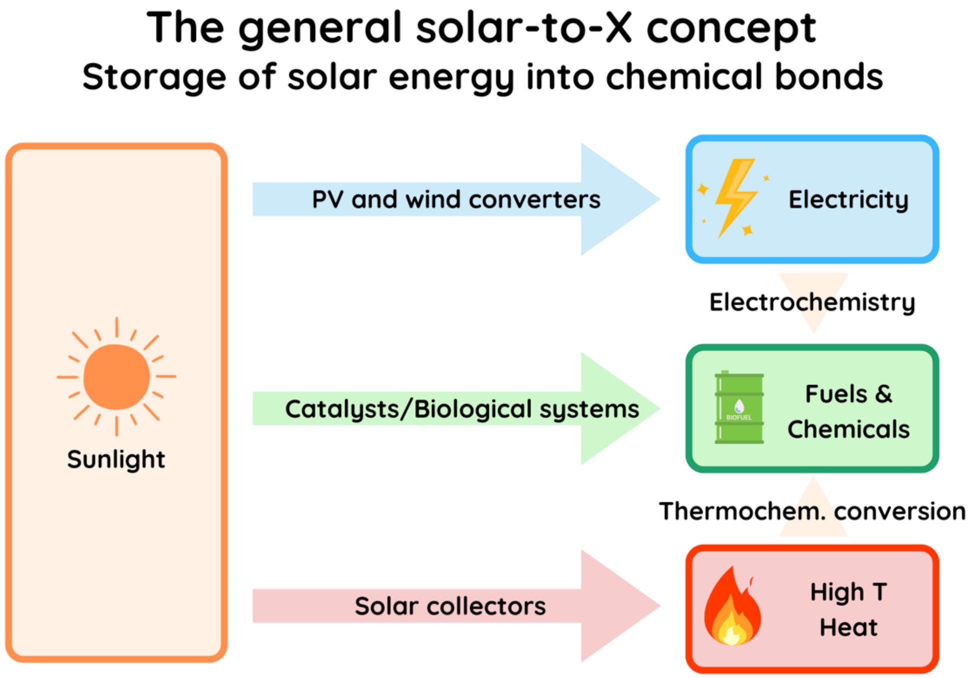
- **Gill Scheltjens** (D-CRBN). This start-up specializes in transforming CO_2 into useful products, utilizing a proprietary **plasma technology**. This technology breaks down carbon dioxide into carbon monoxide and oxygen, which can then be used as a building block for producing **synthetic fuels, chemicals, and materials**. Their project for a pilot plant, in collaboration with ArcelorMittal, BASF, ENGIE and Vopak, would have capacity for up to 1000 tonnes of CO_2 per year, and could offer a simple, safe, plug-and-play solution to decarbonize different industries.

- **Sylvain Cros** (SiFaSol). The project SiFaSol, a pre-seed start-up funded by the Institut Polytechnique de Paris, **develops predictive models that assess the most productive periods for solar energy production** from sub-hourly to yearly scale. The project aims to enhance the efficiency of solar energy systems by creating advanced forecasting tools. These tools use real-time analysis of satellite images to provide more accurate predictions than traditional weather forecasts. By providing more accurate predictions at a high temporal resolution, **SiFaSol contributes to the reliability and efficiency of solar power and solar fuel production systems**.
- **Deepak Pant** (VITO). The European project **VIVALDI** works on the **combination of electrocatalysis and bioelectrochemistry** to produce value-added chemicals. Specifically, it aims to develop processes for synthesizing **acids** such as succinic, lactic, and itaconic acids. These acids are important for various applications, including biofuels, biochemicals, biomaterials, and additives. The project seeks to advance **sustainable chemical production** by integrating these technologies. It showcased successful 1000-hour tests and scaled up the technology for high-pressure fermentation reactors, in a patented process with potential in commercialization.
- **Kristof Verbeeck** (ArcelorMittal). Steel manufacturing is a hard-to-abate sector. The “Steelanol” pilot-plant converts steel mill waste gas into sustainable fuels, particularly ethanol, as part of a pledge in ArcelorMittal to cut carbon emissions by 35% before 2030. After an investment of 200 M€, the Steelanol plant produces 64,000 tonnes of ethanol per year, and contributes to a reduction of greenhouse gas emissions of 150,000 tonnes of CO_2.

3. SOLAR-TO-X: WHERE ARE WE NOW?

While the preceding session showcased ready to be scaled-up power-to-X and CCU technologies and how they address pressing societal needs, this session discussed the state-of-the-art of Solar-to-X technologies, directly producing fuels and chemicals from sunlight. It started with a keynote lecture by Nicola Armaroli, from CNR in Italy, on the perspectives and challenges of this emerging field– particularly the restructuring needed in the energy landscape to adapt to the climate crisis. Additionally, the session showcased current developments in the realm of Solar-to-X, with promising prototypes giving a clear indication of the "best in class" of the field in terms of maturity.

Armaroli started the presentation remarking Schild's previous point on the importance of adaptation and climate resilience. Since the climate crisis has already started, the solutions in the energy landscape not only need to focus on defossilization, but also on sustainable and resilient systems that ensure the independence and security of the supply. This will involve reducing our reliance on fossil fuels for transportation and energy, as well as reimagining the chemical industry. Nowadays, fossil fuels dominate the feedstock landscape in the production of key chemicals, including fertilizers, hydrogen, and important building blocks – including methanol, formaldehyde, and others. While short- to medium-term solutions to source hydrogen and carbon (thus hydrocarbons) encompass electrolytic hydrogen, biomass recycling and CCU, Armaroli suggests for the long-term the straightforward strategy of Solar-to-X – converting sunlight directly to molecules, much as nature itself does.



This comprises different technological approaches, such as electrochemical, photoelectrochemical or photobiological conversion mechanisms. Harnessing solar energy represents a great opportunity for the European economy, said Armaroli. The average solar energy received in the surface of the EU is $5.5 \cdot 10^{15}$ kWh per year – yet we only consume a staggering 0.3% of it ($1.5 \cdot 10^{13}$ kWh per year). Given that nowadays Europe's energy prosperity practically only depends on imported goods, solar is clearly a clean and everywhere available option. As long as Solar-to-X gets the support of funding programs, policymakers, and innovators, current challenges and hurdles, such as too low yields, can be overcome with Europe as a key player in this emerging industry.

After Armaroli's introductory talk, several speakers presented how it works in practice - innovative Solar-to-X solutions, among them the two finalist prototypes of the EIC Horizon Prize, which in 2022 awarded the creation of functional prototypes in artificial photosynthesis.

- **Virgil Andrei** (University of Cambridge). The University of Cambridge reached the final of the EIC Horizon Prize "Fuels from the Sun" with a photoelectrochemical device prototype that uses sunlight to convert carbon dioxide and water into synthetic fuel. These fully-integrated “artificial leaves” demonstrated significant potential for real-world syngas production. The devices show an improved stability (to withstand water and ambient conditions) and scalability, with sizes that reached 10 square centimeters – and even 0.35 square meters for the model 10x10 leaf reactor. Additionally, a flexible design allows lightweight devices to float on the water surface.
- **Nicolas Plumeré** (Technische Universität München). In a recently started EIC Pathfinder project called ECOMO, a consortium of researchers studies biohybrid systems for the valorization of carbon- and nitrogen-based molecules, using both bioelectrocatalysis and fermentation. Among other advantages, using enzymes in electrocatalysis would reduce the reliance on scarce metals and increase the robustness of reactors. Now, biohybrid systems work in pilot plants of up to 300 liters, ready to create value-added chemicals from fermentation.
- **Pau Farràs** (University of Galway). The project FlowPhotoChem looked into the manufacture of a flow reactor for the photoelectrochemical conversion of carbon dioxide and water into value-added hydrocarbons, particularly ethylene. The team integrated three reactors in a simple, single system ready for scale-up and testing. It also established key collaborations with partners in Uganda, to strengthen the ties between the EU and Africa in the path to a clean and just energy transition.
- **Muriel Matheron** (Commissariat à l'énergie atomique et aux énergies alternatives). Also a finalist in the 2022 EIC Horizon Prize, the project EASI-FUEL delivered a scalable solar device, ready to produce green methane. It integrated the production of hydrogen from water and sunlight in a photochemical device with the biological fermentation of hydrogen and CO_2 into methane in a second reactor. This biohybrid process demonstrated a high stability during a 3-day test run, showcasing 21% solar-to-hydrogen efficiency and an immediate utilization, combined with carbon dioxide, to manufacture methane at low temperatures and pressures with a methanogenesis bioreactor. Overall, the model showcased 4.9% solar-to-fuel efficiency, with minimal decay attributed to decomposition of the solar panels. The approach is low-cost and modular, easy to scale-up thanks to 3D printed parts.

4. KEY INGREDIENTS TO TRANSFER INNOVATION FROM LAB TO FAB

After showcasing the technological state-of-the-art, both on the mature and emerging technologies level, this session explored what else is needed to bring an innovation to the market – apart from pure tech development. Bridging the gap between the laboratory and the factory – commonly known as the “lab-to-fab” period – is an important step in the life of emerging technologies. Several steps of maturation and adaptation, as well as detailed life-cycle assessment and techno-sustainability analyses, are needed to bring innovations to the market. This session discussed different examples not only in the field of Solar-to-X, but also in neighboring areas as an example of success, starting with a keynote presentation on the role of Research Infrastructures for accelerating technology and knowledge transfer from **Ennio Capria**, Deputy Head of Business Development at the European Synchrotron Radiation Facility (ESRF) in Grenoble, France. The ESRF produces high-energy synchrotron X-rays to support advanced research in materials science, biology, chemistry, and physics by providing detailed imaging and analysis of samples at the atomic and molecular levels.

Capria emphasized the importance of a strong, collaborative ecosystem, supported by both public and private institutions, for advancing product commercialization. Analytical research infrastructures like the ESRF play a crucial role by providing tools, technologies, and methodologies for rigorous investigation, aiding in everything from data collection and processing to analysis and interpretation. These facilities, alongside electron microscopy, magnetic field labs, and HPC, enable detailed understanding across different scientific scales, supporting both academic researchers and major industry players like ArcelorMittal, Total, and Toyota. They assist in the development of new products and in navigating Marketing Readiness Level (MRL)[4] and Technology Readiness Level (TRL), from the initial concept to market-ready solutions. Capria highlighted a successful case where ESRF’s collaboration led to a novel high-throughput X-ray analysis product that achieved MRL 8 in just a few years. The discussion then continued with three speakers addressing diverse challenges of the “lab-to-fab” process.

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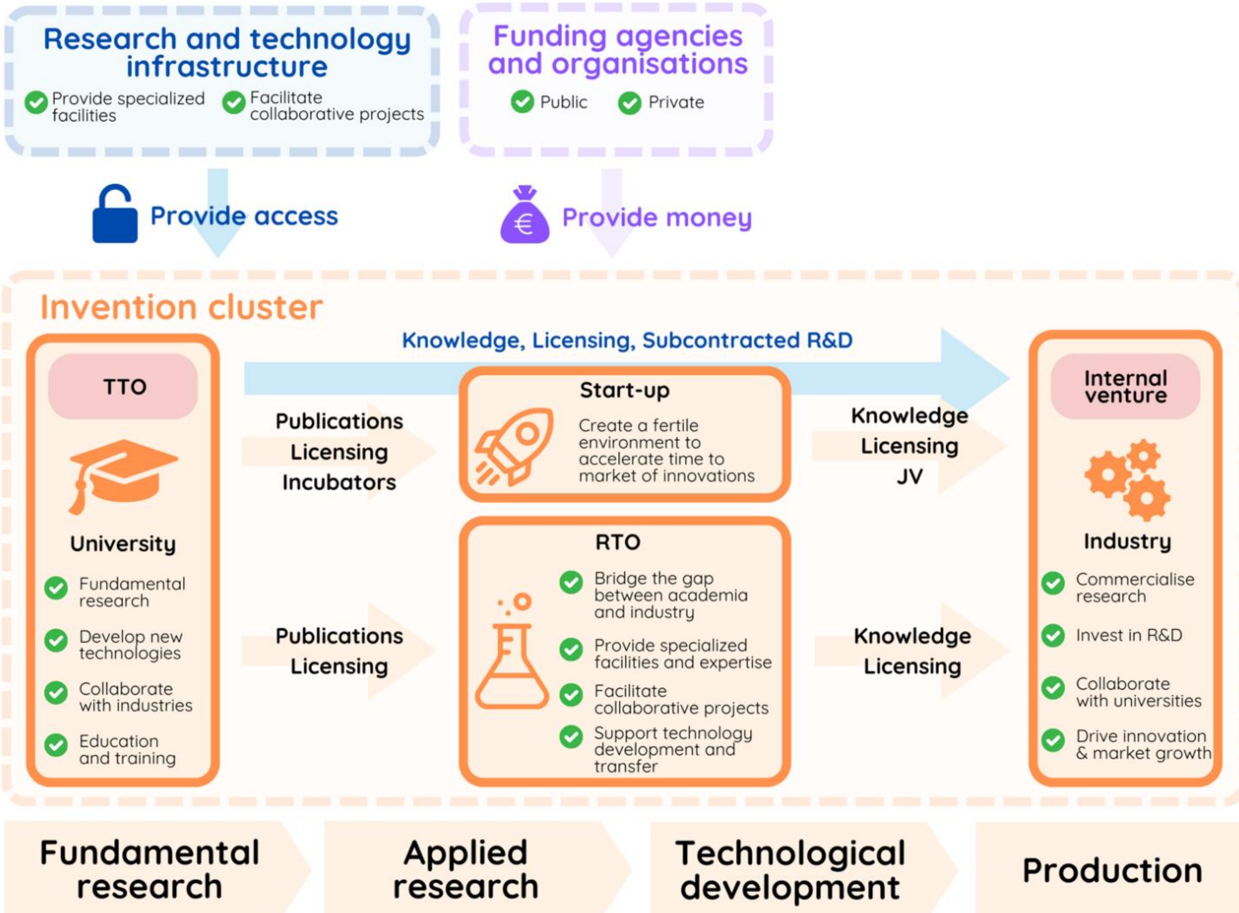
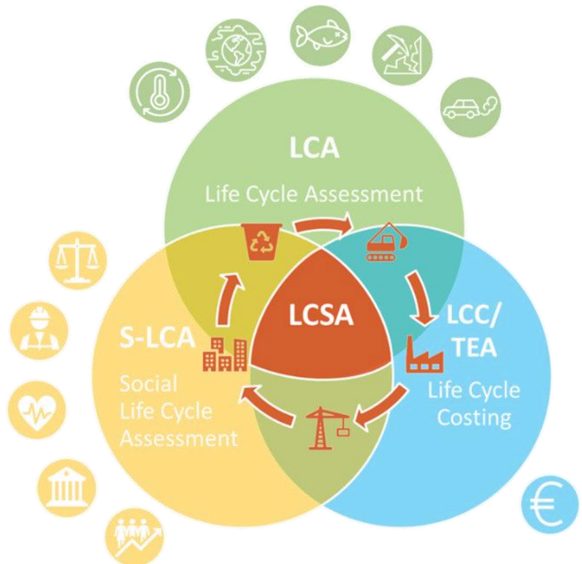
[4] **MRL** usually stands for Marketing Readiness Level, which evaluates how prepared a product or technology is for entering the market, including factors such as market research, customer validation, business model development, and go-to-market strategies. **TRL** stands for Technology Readiness Level, and assesses the maturity of a technology, ranging from the initial concept to full commercial deployment. See more on page 23.



- **Miet Van Dael** (VITO). The talk stressed the importance of having an early, harmonized and transparent sustainability evaluation of emerging technologies. This includes the environmental, economic as well as social impact. Having such a harmonized sustainability framework leads to a rational and standardised evaluation of results. The main goal is to identify the parameters that have the highest impact on the sustainability of solar-to-X technologies (i.e., the "hot spots"). Miet highlighted the importance of asking the right questions to clearly understand which technologies fit best in which situation. The insights will help policymakers steer the decision-making process in the right direction and identify the added value of different technologies. "We must understand the parameters that influence the sustainability impact along the value chain already at an early stage," she said.



- **Tom Aernouts** (imec). "Lab-to-fab" takes time, as highlighted in this presentation for perovskite solar cells. Named one of Science's "Top 10 Breakthroughs" in 2013, this field is still struggling to get into the market, despite the meteoric rise of efficiency since its discovery. The technology transfer process requires a strong investment and a long-term commitment throughout the value chain. In the case of perovskites, imec works in stable and scalable technologies from small laboratory set-ups to large industrial facilities including a 1500 square meter module for photovoltaics and batteries. Among other things, this enables the control of the complete process, developing and investing only in technologies with potential for adaptation to standard industrial manufacturing processes. Whereas most research labs prioritise "record-breaking" papers and increasing the performance of small cells, few focus on large-scale solutions. So far, Imec's results show promise, with panels of almost 1000 square centimeters in size that exceed 20% in power conversion efficiency.

- **Laura Torrente-Murciano** (University of Cambridge). Insisting on the importance of re-imagining the chemical industry, Torrente-Murciano highlighted intermittency of the renewable energy supply as the biggest technical and economical challenge. "Until the cheapest options are the best options against the climate crisis, we won't see change," she said quoting climate scientist Katherine Hayhoe. In this sense, ammonia could play a key role as a carbon-free energy vector and a fuel, with a higher energy density than liquid hydrogen and LNG, almost comparable to petrol.

  Additionally, ammonia is already a key chemical feedstock with an existing global infrastructure for storage and transport, which could be repurposed for processes like cracking, feeding of fuel-cells and direct combustion. An interesting approach would involve redefining ammonia production in a smaller, decentralized scale, prioritizing single-vessel processes ready for intermittent operation and renewable energies. Her start-up "Cambridge Innovations in Ammonia" is exploring the possibilities of commercializing small-scale ammonia production, with the support of Bill and Melinda Gates' initiative "Breakthrough Energy", among other funders.

5. DEEP DIVES

5.1 The importance of integrating TRL and MRL in a new product

Led by Ennio Capria and Joachim John

In today's fast-paced and highly competitive market, the development of new products and services requires a holistic approach that goes beyond technological advancements alone. While the Technology Readiness Level (TRL) is a well-established framework for assessing the maturity of a technology, it is equally crucial to consider the Marketing Readiness Level (MRL)[5] to ensure efficient and sustainable innovation. Just as technological development must be meticulously designed and structured, business development must be aligned with specific objectives and needs at each phase of the development process. Integrating TRL and MRL is essential for the successful and sustainable development of new products and services. This balanced approach ensures that technological and business developments support each other, leading to efficient market introduction and long-term success.

Focusing solely on technical development without adequate business support can lead to unnecessary delays in bringing a product to market. This extended timeline increases the risk of the product becoming obsolete before it reaches consumers, eroding its competitive edge. Conversely, accelerating business development without matching technological progress can create over-expectations in the market. If the product fails to meet these expectations, it can lead to customer frustration and loss of trust. Recovering from such damage to reputation requires substantial resources and may not always be possible.

TRL and MRL are interdependent and must evolve hand in hand. As technology advances through the TRL stages, parallel progress in MRL ensures that the market is prepared to accept and adopt the innovation. This co-evolution prevents the common pitfall of having a technologically superior product with no market traction. A business must develop robust

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[5] An ambiguity exists on the meaning of MRL which is released when specifying the context of application. The **Marketing Readiness Level (MRL)** differs from the Manufacturing Readiness Level in that it focuses on the market readiness of a product or technology rather than its manufacturing processes. The **Manufacturing Readiness Level (also commonly abbreviated MRL)** assesses how prepared a manufacturing process is for producing a product at scale, including aspects like process development, production capability, and quality control. MRL in the marketing context is concerned with the product's readiness for market introduction and commercial success, while MRL in manufacturing is about the readiness of the production process.

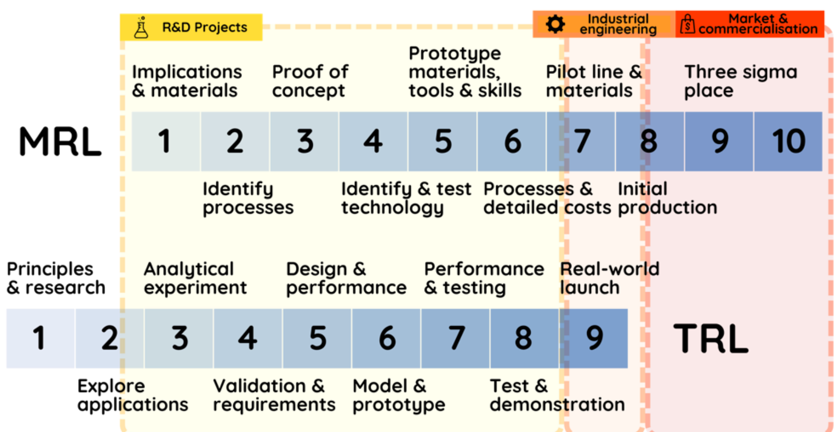
strategies, including market research, customer engagement, and competitive analysis, from the early stages of product development. This ensures that as the technology matures, there is a clear path to market adoption and growth.

Proper resource allocation is essential for both technological and business development. This includes financial investment, talent acquisition, and strategic partnerships. Resources should be aligned with the specific needs and objectives of each development phase to maximize efficiency and impact. The adoption of MRL monitoring alongside TRL provides the management team with a structured process and modus operandi for steering the activities required to address market growth throughout all phases of new product or service development. Effective business development follow-up must consider not only market traction but also internal factors such as capacity, motivation, and alignment with the company mission.

Business development and technical development activities are typically accomplished by dedicated teams with complementary capabilities, motivations, and skills — namely, business developers and engineers. Achieving a harmonious approach to TRL and MRL growth requires these technical and business teams to work synergistically and cooperatively. This integration ensures that technological advancements are supported by a ready market and that business strategies are grounded in realistic technical capabilities. By aligning resources and strategies with the specific needs of each development phase, businesses can reduce time to market, maintain their competitive edge, and foster long-term customer trust and satisfaction.

The breakout session provided valuable insights into the participants' understanding of TRL and MRL, as well as their potential application in the innovation process. The group composition was a positive surprise, as it was well-balanced between individuals from basic and applied research and industry. This mix allowed for diverse perspectives on the challenges and opportunities related to these readiness levels.

The first conclusion drawn from the session was that, while the majority of participants were familiar with the TRL concept—widely used to assess technical maturity during research and development—there was very limited knowledge of the MRL framework. MRL, which is more relevant in the phases of commercialization, evaluates how ready a technology is for the market. This gap in understanding highlighted the need for more awareness of MRL, especially in organizations looking to bring innovations to market. During the session, the differences between TRL and MRL were further clarified.[6] TRL is commonly used in R&D to measure the technical readiness of a technology, whereas MRL focuses on the readiness for manufacturing and market entry. This distinction helped participants better grasp how each framework serves different stages of the innovation and commercialization pipeline.



The group was also asked which roles within their companies contribute the most to advancing both TRL and MRL, and what obstacles they encounter in improving these levels. The main obstacles identified for the adoption of the MRL concept were resistance to change, lack of competence, company culture, unclear benefits, resource constraints, and difficulties in cross-functional collaboration. These challenges were spread fairly evenly across the responses, indicating that no single barrier dominated the conversation, but that a combination of factors can impede the effective implementation of MRL.

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[6] Graphic adapted from: Basu, B., Ghosh, S. (2017) in Biomaterials for Musculoskeletal Regeneration, Springer Nature, DOI: 10.1007/978-981-10-3017-8_11

In conclusion, while many participants were not initially familiar with the concept of MRL, they found it highly relevant and expressed interest in applying it within their organizations. In particular, they saw the potential value of using MRL in programs like the EIC accelerator to better guide the transition of technologies from development to market readiness. This final takeaway underscored the importance of educating stakeholders on MRL to enhance innovation strategies and commercialization processes.

5.2 Techno-sustainability assessment for emerging solar fuel technologies

Led by Miet Van Dael and Carina Faber

In today's rapidly evolving technological landscape, the success of new innovations hinges not only on their technical excellence but also on a range of non-technological factors. These include sustainability, legal frameworks, societal acceptance, and geopolitical concerns. As technology development increasingly intersects with broader societal issues, it becomes crucial to adopt an approach that considers these dimensions. Currently, the EIC supports the development of a new methodology to integrate these factors into the innovation process. The goal is to combine technological advancements with socio-economic and environmental sustainability considerations and to ensure that innovations align with European core values and deliver positive, long-lasting societal impacts. In this break-out session, the main assumptions of the developed framework have been presented and discussed with a diverse group of leading experts from academia and industry to ensure future usability and impact already at an early stage.

Despite the availability of environmental, economic, social, and even integrated assessment methodologies and methods, there is no generally accepted harmonized template and framework that can be used for emerging technologies. Sustainability assessment for emerging technologies is challenging because of the lack of data, the uncertainty in the development pathway and often a lack of established standards. Nevertheless, having such a template and framework available would be very beneficial for the field of solar-to-X. The latter is characterized by a plethora of technological approaches and products, and singling out the added value compared to more mature energy technologies is complex.

Having a harmonized template with a clear and transparent indication of system boundaries, methodological choices, default values and other assumptions can speed-up the innovation process. It can facilitate and guide the communication and common interpretation of the added value of proposed emerging technologies between different stakeholders such as scientists, business developers, future users and potentially funding bodies. It will allow users to have guided discussions on questions like: 'what is the best route to which molecule?', 'where does my innovation add something to what is already existing?', 'what if legislation puts certain restrictions, adds costs or creates a new market?', 'what targets should we reach to be competitive on the market or have a lower environmental impact?', or 'which scale and location should we target'. Facilitating these discussions by quantifying the effects already early in the development and allowing to add more details and accuracy across the different innovation stages is the main goal of the template and framework. The calculations are aimed at understanding which parameters add most to the different impacts (i.e., economic, environmental, and social), rather than calculating the exact impact. Sensitivity analysis is the most important step as it allows us to answer questions as stated above and understand the context in which an emerging technology can really play a role.

Considering the main goal, the template and framework should be used after the proposal is granted and budget can be foreseen to use the template and framework to steer the discussions within the consortium. In other words, it is developed for the benefit of the applicants. When used correctly, it can even help the applicants to pass projects from the fundamental R&I level to the next level in the innovation journey and to find public and private investors by building a convincing, quantified story. It should be clear that the techno-sustainability assessment is not developed for the evaluation of EC call proposals, nor is it developed to collect user data.

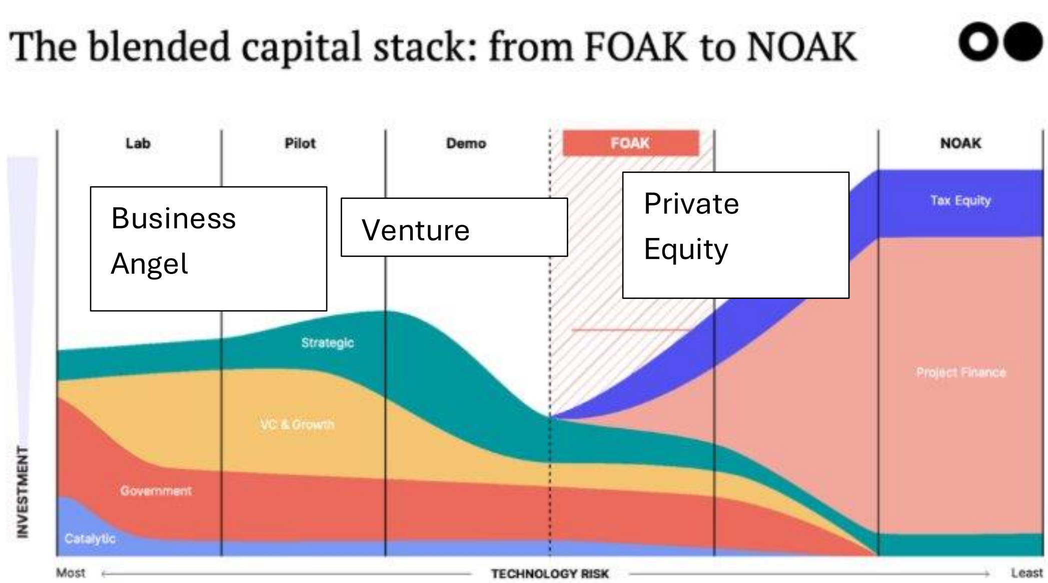
The template is developed in Excel and based on the principles of techno-economic and life-cycle assessment. It has a fixed structure in terms of worksheets that can be used across different projects. It contains several elements that should be completed and allows transparency in the scope, system boundaries, geographical scale, methodological choices, etc. Furthermore, users are encouraged to be transparent in the assumptions and references to facilitate discussions. It is constructed in such a way that an increased level of detail can be added. In the beginning calculations can for example be done based on thermodynamic limits. This gives an indication of how the system would perform in its optimal configuration. In the next stage more details can be added. As such a stage-gate principle can be introduced to discuss the results amongst different stakeholders, make substantiated decisions and help to define the technology roadmap.

6. FUNDRAISING STRATEGIES FOR SCALING UP

by Francesco Matteucci, European Innovation Council

The innovation journey of a scientific innovation, so called deep tech, is composed of all the activities performed to transform an idea developed within a scientific laboratory into a marketable product. There are different routes, so called exploitation strategies, to implement the innovation journey, such as licensing the know-how or setting up a company that will further develop the idea. The deep tech innovation journey is not a linear process, it requires knowledge and time, and it necessitates to overcome many challenges such as setting up the right team, properly protect the know-how, implement a design-build-test and learn approach, and fundraise the adequate amount of money at the right time.

The goal of the “coffee with money” panel was to bring people from different investment vehicles together with scientists and scientific entrepreneurs to make participants familiar with the diverse financing options that can be considered when starting or implementing their deep-tech innovation journey in the green sector.



Capital availability against project stage (Source: Sightline Climate)

The shown figure was the driver of the panel discussion as it summarizes the main fundraising options during the development of a deep tech, and how the blend and the availability of capital changes over time. In this figure, the innovation journey has been divided in a simplified way in five main stages:

1) Laboratory phase (approximately from TRL 1 to TRL 3);
2) Pilot or proof of concept phase (from TLR 3 to TLR 4);
3) Demo or prototype phase (from TLR 4 to TRL 6);
4) FOAK or *first of a kind* phase (from TRL 6 to TRL 7); and
5) NOAK or ninth of a kind phase (from TRL 8 to TRL 9).

In the laboratory phase, the main funding options are public/governmental grants or philanthropic grants. It is relevant to highlight that these funding options are not primarily driven by financial criteria, such as return of investment, but mainly by other strategic factors such as geographic autonomy for a certain vertical area or the creation of a vertical ecosystem. As the technology is validated at lab scale, if the exploitation strategy is to found a venture/company, then the founders may get support from venture studios or venture building to set up the best team, a crucial pre-requisite to successfully continue the innovation journey. To advance in the innovation journey and go the prototype or pilot phase, the venture has different fundraising options ranging from debts, mainly with bank or governmental institutions, or dilution, meaning exchange money for equity, from different entities such as venture studio, incubators, accelerators or from individual investors called business angels that will provide as well mentoring and business acceleration services (e.g.: stakeholders engagement, intellectual property and tech to market matching strategy). Once the technology has been successfully proven at the pilot stage, early-stage venture capitalist investment vehicle or the so-called strategic investors, corporate or global leaders in a vertical area/category who looks not only at financial return but also at lateral investment benefits such as bringing in their ecosystem additional experienced human capital, are dilution funding options. As the innovation journey goes from the pilot to the demo phase the venture can fundraise from different venture capitalist, strategic or governmental vehicles and has to be ready for the critical FOAK (first-of-a-kind) step. This step, where something is still new (e.g. the technology, the business model, the application) though it would not be "First", is critical because it still includes the combination of high risk and high capital requirement so falling between company or equity growth and project finance. At FOAK phase it may appear new financial investors such as "risky" project investors that will work with "expensive" either debt and/or equity at the project level because the goal is to prove that the "products" made at small can be done at commercial scale from reliable supply chains and delivered/sold at market prices and at quality standards, meaning product market fit. If FOAK is successful and venture bridge to NOAK phase then there re will be "typical" de-risked project investors including large banks, pension or infrastructure funds that will provide comparatively cheap capital. Projects will be no longer built with equity but ideally up to 80% of debt. At the NOAK phase investors will look for different KPIs from financial investors as they will mainly look not at the company growth but at delivered and operated projects as intended showing that the technology always works.

The panel discussion was animated by the presence of the following expert panellists: Lipsa Nag, from Marble, a Venture Building focused on Climatech, Guus Keder, a business angel and private venture capitalist (VC) and Ekke Van Vliet, representing the EIC Fund, the first VC of the European Commission. The main panel's take-home messages for the different stakeholders of the European ecosystem of innovation were the following:

For scientists: start thinking as soon as possible at: a) the final application of the technology, b) the technology value proposition, c) protecting the ideas through proper intellectual properties tools and then publishing the discovery in scientific papers, not the contrary, d) map and engage with all the stakeholders that may provide relevant suggestions/know-how for the technology innovation journey.

For prospect entrepreneurial scientists: innovation is a team sport so there is no innovation journey without the right team including experienced advisors and other relevant stakeholders. Entrepreneurial scientists do not need to re-invent the wheel but properly study what has been already developed within the area as well as map the competitors' strategy. When fundraising, it is paramount to be aware that the main differences between business angels and private VC are: a) the former usually invests their own money, while the latter manages someone's else money; b) business angles usually invest with ticket size smaller than 250kEuro in an early-stage idea providing tech or business development mentoring services with a long time return of investment, while VCs invest with ticket size bigger than 250kEuro with 5-10 years as investment period and their team mainly has financial or legal background. Corporate VCs may have different investment strategies than "traditional" VCs.

For deep tech investors: The deep tech innovation journey for climate technologies needs more time then foreseen in standard VC models. Climate technologies are strongly impacted by policies, so a collaboration with policy makers is highly recommended. The EIC Fund is a Governmental Venture Capital (GVC) fully owned by the European Commission, with an approximate budget of 600mln euros each year (2021-2027) with the following main characteristics:

- Not leading private crowding-in investor with a private leverage of at least 1:1 (1 euro of private investment for 1 euro of EIC Fund investment),
- "Patient" investor with a 10 years' and beyond time horizon aimed at supporting early-stage deep tech companies that are demo phase (TRL>5) with sufficient time to take deep tech to the market.

The panel showed how the European ecosystem of innovation is trying to provide to Cleantech scientists and entrepreneurial scientists as many funding options as the other worldwide ecosystems do. The recent set up of different GVCs, such as the EIC Fund, is de-risking the private VC so reaching their policy vision of stimulating more private investors to support European start-ups.

Two enabling factors of clean- and deep-tech start-ups success, team and money, were discussed highlighting the need on one side to invest in continuous upskilling programmes as well as doing the best to recruit and retain the "right" people, so to have the best team. On the "money" side start-ups need to properly be acknowledged on the "mission & vision" of the different investors trying to have them both as financiers and mentors.

7. THE DEVICES OF TOMORROW

After having discussed the state-of-the-art on the first day, the workshop kickstarted with a session on the future avenues of Solar-to-X on the second day. These included strategies combining computational and experimental techniques to accelerate the design and development of sustainable solutions.

Rachel Armstrong, professor for regenerative architecture at KU Leuven, opened the session by presenting the challenges of implementing novel renewable energy technologies in cities. Over half of the world population lives in cities, and this number is expected to rise to 66% before 2050. This creates challenges in terms of climate neutrality and contributions to carbon emissions. However, it also represents an opportunity – cities could become a testbed for innovation and pilot projects in renewable energy, plus they serve as technological hubs to test ideas before global scale-up, according to Armstrong.

In her designs, she draws inspiration from microbial communities, which have thrived by adapting to changing ecosystems and working together for collective benefit. This concept led to EU-funded projects like "Living architecture," which used bioreactors to turn waste into electricity, valuable products, and clean water, reducing pollution and supporting a circular economy; “ALICE”, which developed a digital interface to interact with microbial communities; and “Microbial Hydroponics”, which designs a prosthetic rhizosphere to optimize carbon and nitrogen fixation in hydroponically grown plants without the need for artificial fertilizers.[7]

Another example blended science and art, showing how microbes and humans form a single ecological unit in homes. Armstrong highlighted the potential of microbial hydroponics for greener cities, where systems convert carbon dioxide into biomass and nitrogen into useful products like amino acids and proteins. These systems could also produce bioplastics and reduce reliance on fossil fuels by creating energy and materials locally.

Bio-based systems could harness solar power and convert atmospheric molecules into chemical fuels, supporting decentralized production of electricity, fuels, and resources. These Solar-to-X technologies could transform waste into clean energy and renewable

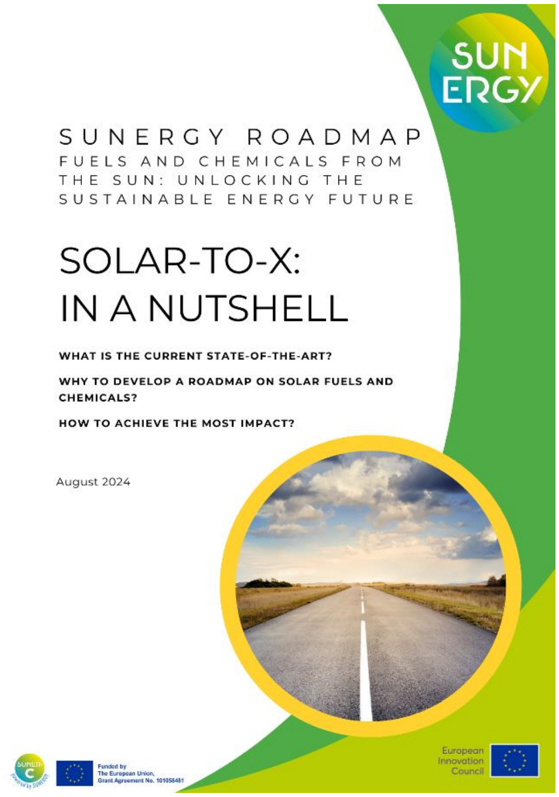
[7] **Living Architecture** is Funded by the EU Horizon 2020 Future Emerging Technologies Open programme (2016-2019) Grant Agreement 686585. **The Active Living Infrastructure: Controlled Environment (ALICE)** project is funded by an EU Innovation Award under EU Grant Agreement no. 851246. **Microbial Hydroponics: Circular Sustainable Electrobiosynthesis (Mi-Hy)** is Funded by the European Union under Grant Agreement number 101114746.

resources, making cities more sustainable and resilient. By integrating living technologies, we can promote human-microbial symbiosis for truly regenerative, circular economies.

Building on this vision for future cities powered by renewable energy, the subsequent speakers explored how cutting-edge technologies—like fully autonomous devices, high-throughput computing and technological road mapping — can further transform not just urban living, but entire systems. From energy grids to supply chains, transportation networks to food production, these innovations promise to revolutionize the way we manage resources, optimize efficiency, and minimize environmental impact. By integrating these technologies, we can create smarter, more resilient infrastructures that support a sustainable future on a global scale.

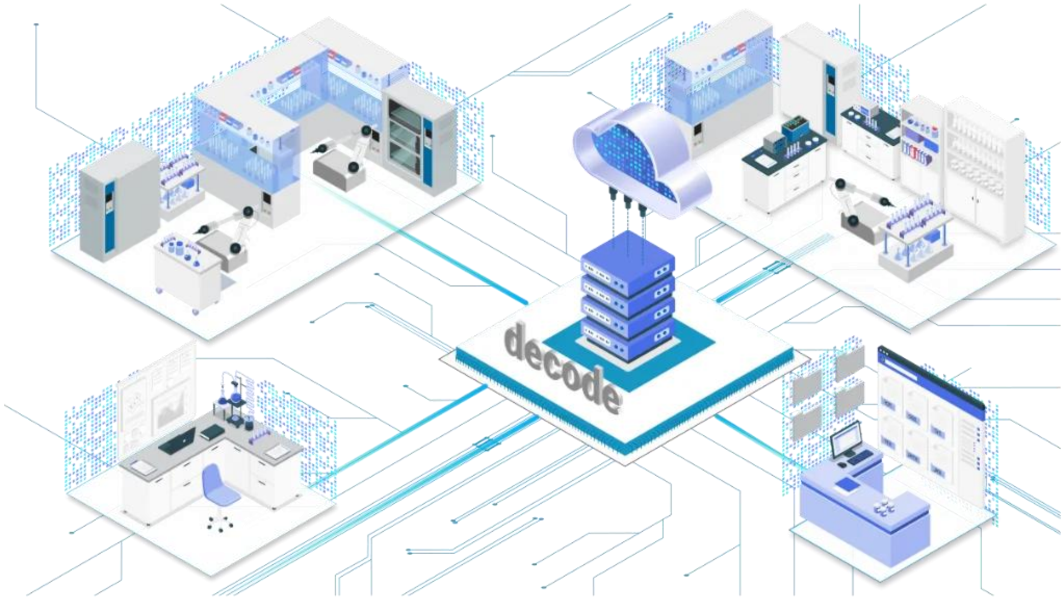
- **Iker Aguirrezabal** (University of the Basque Country). The project CATART, funded by the EIC, is designing an autonomously running reaction robot driven by artificial intelligence to convert water and carbon dioxide into value-added chemicals. The main advantage of this approach is the use of quantum dots (QDs) to harvest photons directly, instead of using PV devices to get electricity first and feed the reactor later. Additionally, an automated algorithm will collect information from the results and retrofit the reaction with the most successful parameters – adapting to different environments and conditions on-demand.
- **Joanna Kargul** (University of Warsaw), **Frédéric Chandezon** (Commissariat à l'énergie atomique et aux énergies alternatives) and **Han Huynhthi** (ENGIE). For policymakers and investors, it is essential to have clear strategies towards the efficient implementation of Solar-to-X solutions, as well as evidence-based reports towards informed decisions in legislation. In this sense, the SUNERGY platform and the SUNER-C consortium have served as a model in the community, incorporating over 300 experts from academia, industry, and society working together in the topic of Solar-to-X and artificial photosynthesis. Among other initiatives (including workshops, events, and communication and dissemination actions) during the Solar-to-X event in Genk the SUNERGY initiative announced the publication of a comprehensive roadmap around the technology.

This document –entitled “Solar-to-X: In a nutshell”– will feature a comprehensive analysis of the state-of-the-art of several technologies in CCU and artificial photosynthesis and provides a pathway towards achieving the maximum impact in the European framework.



- **Michael Eikerling** (Forschungszentrum Jülich). Computer-assisted material science will play a key role in creating new materials and devices for Solar-to-X solutions. Approaches such as materials modeling, artificial intelligence and digital twins will contribute to design, characterization, and lifecycle assessments. For example, the European DECODE[8] project, part of Horizon 2020, focuses on advancing energy materials through decentralized cloud-based labs. This project connects labs and computational resources to overcome coordination challenges and streamline industrial-scale development. Coordinated by Forschungszentrum Jülich GmbH and involving partners like Bosch, DECODE aims to accelerate materials discovery by enabling real-time collaboration and data sharing. It supports innovation with high-throughput experimentation, automation, and digitalization, which is crucial for developing sustainable energy solutions and addressing climate change.

[8] https://cordis.europa.eu/project/id/101135537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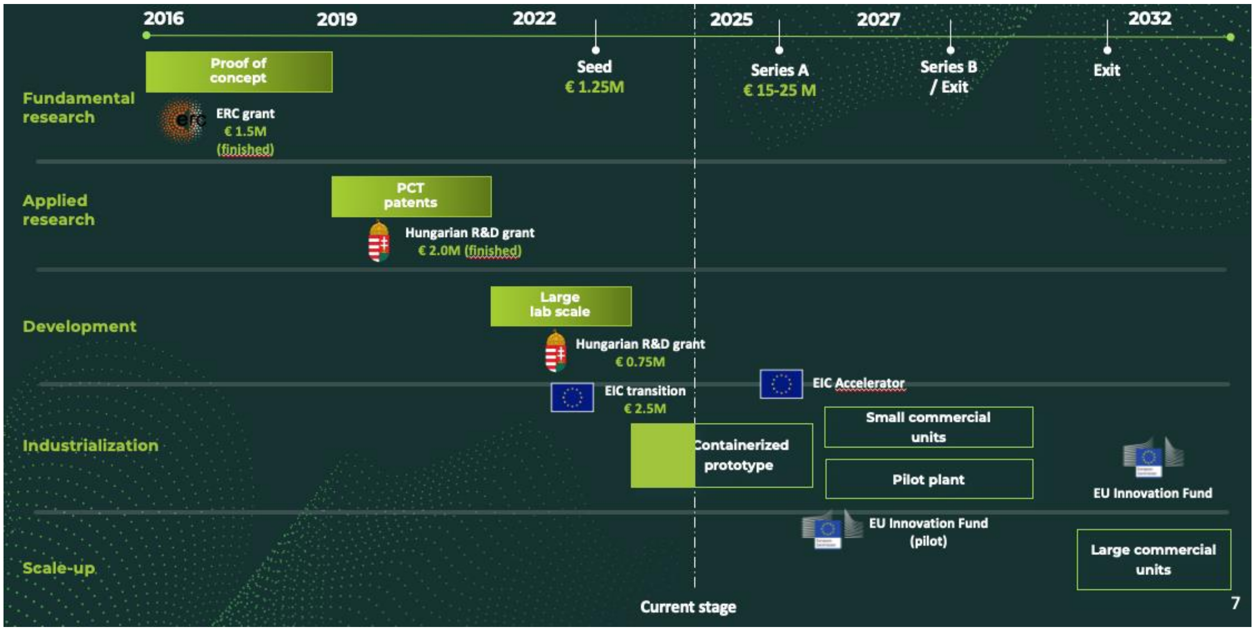
8. TECHNOLOGIES VS. EXPECTATIONS: FAIR BENCHMARKS AND STANDARDS

Assessing whether Solar-to-X technologies and devices deliver on expectations heavily relies on fair frameworks for benchmarking. Otherwise, comparisons and competitions become arbitrary – the industry needs standards for a successful implementation of sustainable solutions, and so do policymakers, who rely on clear targets and KPIs for the incorporation of new technologies into regulation. This session counted on a diverse panel of speakers from academia, start-ups, industry and patenting to highlight the importance of benchmarks and standards in innovation, especially around new and emerging technologies like Solar-to-X, Power-to-X and CCU.

Csaba Janáky, university professor and co-founder of eChemicles, a start-up company focused on the conversion of carbon dioxide into value added products, opened the floor by sharing their innovation journey to bring novel electrolyzer technology to the market. One of the main products of eChemicles electrolyzers is carbon monoxide (CO). The latter is an interesting chemical feedstock for different industries, including steel manufacturing, fuel refineries, plastic production and renewable chemicals. Starting from a small lab-scale model, eChemicles developed stacks and assemblies ready to jump into large-scales. A "container"-like prototype is foreseen before 2025, thanks in part to the support of an EIC Transition grant[9] and funding from the Hungarian government.

However, before moving to bigger scales, Janáky remarked the importance of benchmarking in different settings. For example, technological and technoeconomic benchmarks provide information on competitors in the field of Solar-to-X, including similar technologies in carbon utilization. In this sense, the development of a standard is currently a priority, since different labs currently compare different KPIs and measurements, which is rarely the case for other technologies and often leads to misleading reports and papers.

[9] Lab-to-tech transition of the current best low temperature electrolyser technology for CO_2 reduction to CO using solar energy: https://cordis.europa.eu/project/id/101099284/reporting



eChemicles is working with a series of labs and research groups across Europe to develop and promote a standard in the field, focused on durability, homogeneous testing conditions, and a reproducible measurement protocol for a given set of components. The aim is to publish the results openly in a position paper, to facilitate the deployment and adoption of the new standards throughout the community. Additionally, business benchmarks often clash with technological needs, and instead purely focus on feasibility and viability (as well as potential clashes with regulatory frameworks). Moreover, suppliers have different standards in terms of purity, efficiency, and specific needs, which drive the benchmarks in different directions depending on factors like competition and market availability. “Benchmarking can’t just be a paragraph in research papers,” says Janáky. Instead, it should emerge from transparency, collaboration and consensus across parties. Only then will CCU technologies prove viable for the green transition. Efficient and coherent benchmarks and standards will catalyze not only commercial applications, but also the implementation of policy and regulation to encourage the adoption of sustainable solutions across Europe. The keynote speech was followed by interventions showcasing concrete development results and the need to introduce standardized procedures to measure and compare device performance.

- **Moritz Schreiber** (Total Energies). A coherent and comprehensive analysis of benchmarks and key performance indicators (KPIs) helped the researchers at Total Energies to identify the most promising pathway in the production of synthetic aviation fuels (e-SAF).[10] Currently, several pathways to produce e-SAF are explored – including thermochemical, electrochemical and biological routes – searching for the most competitive route both technically and economically. Electrochemical CO_2 conversion to ethylene to e-SAF was identified as a potentially competitive route. A detailed KPI analysis allowed to determine those process steps that require special attention. Namely cell voltage and device lifetime are both bottlenecks in the scale-up of the technology and bare great potential for optimization. Such thorough benchmarking procedures are still a rare practice, but the way forward to assess R&I priorities and to accelerate market readiness.

- **Ifan Stephens** (Imperial College London). While the upscaling of electrochemical technologies to produce hydrocarbons, such as CO or ethylene, currently suffers from the lack of standard measurement procedures and harmonized protocols to fine tune the devices, the electrochemical production of ammonia faced for a long-time severe challenges of reliably detecting and quantifying ammonia synthesis via electrochemical nitrogen reduction. Due to the small quantities of ammonia typically produced in such experiments, one easily confuses true ammonia generation with contamination from ambient nitrogen or other lab sources. Professor Ifan Stephens from Imperial College London has made significant contributions to the development of standardized measurement protocols for electrochemical ammonia production. Stephens and his collaborators developed a rigorous protocol that includes the use of isotopically labeled nitrogen to accurately track the nitrogen conversion process. This method ensures that ammonia production can be correctly attributed to electrochemical processes and not experimental artifacts. His research emphasizes the importance of eliminating contamination from the nitrogen gas supply and other sources, thereby providing clearer and more accurate results for researchers working on sustainable ammonia synthesis methods as an alternative to the traditional, energy-intensive Haber-Bosch process. This work plays a crucial role in advancing the field of nitrogen reduction reactions by providing reliable and

[10] SAF stands for Sustainable Aviation Fuels and the **definition** is set out in the ReFuelEU Aviation Regulation. It covers different drop-in aviation fuels compliant with the sustainability criteria of the Renewable Energy Directive (RED):

- **Synthetic aviation fuels** from renewable hydrogen and captured carbon, often abbreviated e-SAF;
- **Advanced biofuels** from waste and residues;
- **Biofuels** produced from oils and fats;
- **Recycled carbon aviation fuels**.

For more information, please refer to the ReFuelEU regulation.

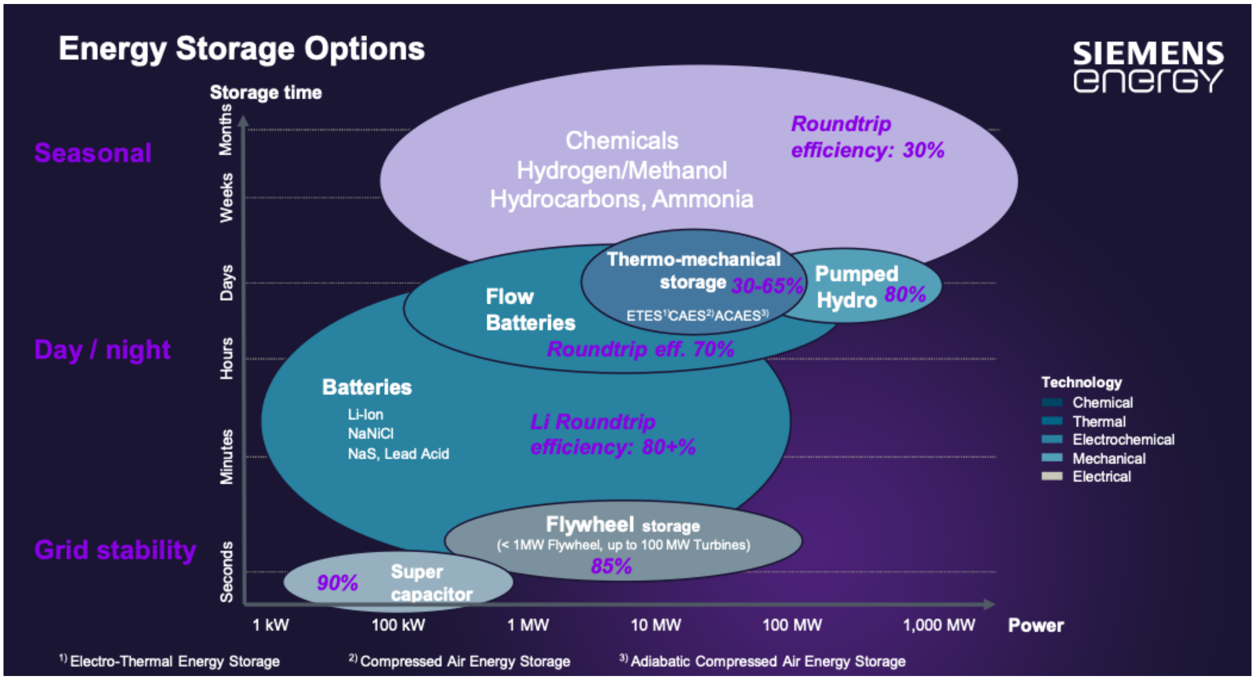
reproducible results, which is critical for the development of sustainable energy and chemical processes

- **Luis Sanz Tejedor** (European Patent Office). The participation of the European Patent Office (EPO) in the workshop demonstrates the importance of intellectual property in technology transfer, as well as the interest in deep tech innovations from the second largest intergovernmental institution in Europe. In this session, EPO presented a newly developed tool called the "Deep Tech Finder," which helps identify start-ups, including those working on carbon capture and related sustainable technologies. This platform blends patent data with financial information on European startups, filing patent applications with the EPO. It sheds light on ventures that have the potential to bring new technology to market. The tool harnesses EPO's expertise in patent information and helps potential investors and business partners to find out what inventions are being developed in specific technology fields and assesses their levels of protection by European patents. By identifying key players in carbon capture and other critical technologies, it can facilitate the adoption of best practices and expedite the commercialization of innovative solutions. The **EPO Deep Tech Finder is available online for free**, alongside a demonstration video that showcases the uses and capabilities of the platform. Additionally, the EPO also publishes reports regularly with an extensive overview of different technologies, many of which are related to Solar-to-X, such as joint studies with the International Renewable Energy Agency (IRENA) on electrolysers for hydrogen production and offshore wind energy.

9. WHAT ELSE IS NEEDED? INSIGHTS FROM INDUSTRY AND GOVERNMENTAL INITIATIVES

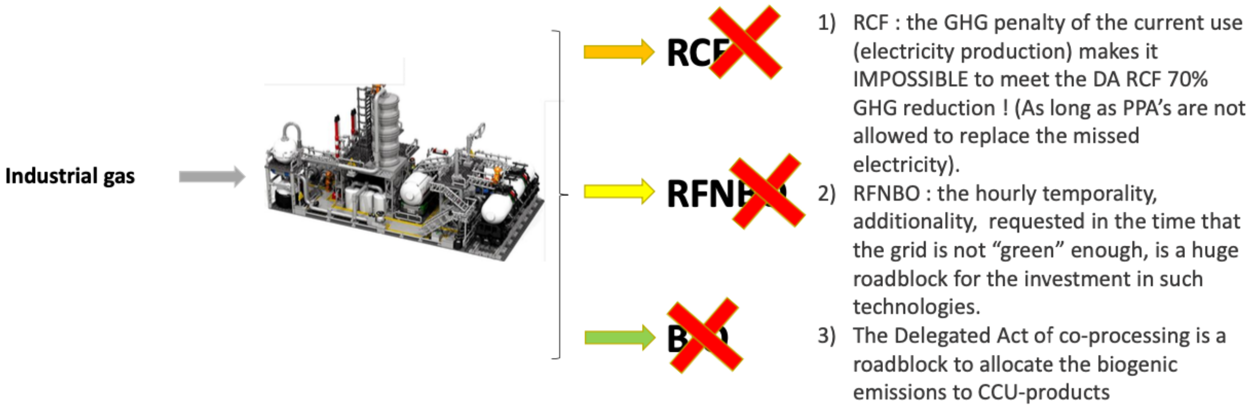
The last session of the workshop provided a comprehensive overview of the future requirements for advancing green molecules, as seen from both industry and government perspectives. It highlighted the need for regulatory and legislative adaptations to foster Solar-to-X solutions. From the industry's viewpoint, there is an increasing demand for green hydrogen and other sustainable molecules to defossilize diverse sectors like energy, transport, and heavy industries. However, key challenges remain, particularly in scaling up production and reducing costs. Legislative frameworks offer some support, but they are insufficient to drive the level of innovation needed. More robust and stable policies are required to lower investment risks and create a conducive market environment. This was complemented by the presentation of a holistic techno-economic assessment of artificial photosynthesis, commissioned by the German government, adding further depth to the understanding of these emerging technologies. Presentations from researchers and policymakers in the U.S. offered a valuable perspective, comparing strategies and regulatory frameworks with those in Europe.

A keynote speaker from industry, Prof. Maximilian Fleischer, CTO at Siemens Energy, provided a sensible overview of the scale of the sustainability challenge, offering a grounded perspective that tempered the optimistic promises discussed. This helped place the ambitions and efforts into a more realistic context, emphasizing the need for pragmatic approaches to solving large-scale environmental and energy challenges. He noted that while our planet has abundant energy resources—solar energy alone could meet our needs 1,200 times over—the situation is far from ideal due to cost and productivity challenges. Covering all our energy needs would require a photovoltaic installation about the size of France, which could cost up to three times the U.S. GDP. However, priorities might need to shift: solar power costs are expected to decrease, while oil and coal prices are likely to rise due to scarcity. Increasing the share of renewables could balance the energy landscape and lower electricity prices compared to imported LNG. Storage and transportation methods also need improvement; chemicals and synthetic fuels offer better long-term stability than batteries and pumped hydro solutions, though their efficiency remains low.



Solar-to-X and Power-to-X solutions must prioritize integrating and simplifying the value chain, focusing on more efficient pathways to synthetic hydrocarbons. For example, directly converting carbon dioxide into fuels and feedstocks through electrocatalytic and biocatalytic methods significantly streamlines the process. However, carbon capture technologies, especially direct air capture (DAC), need major advancements to make a substantial impact. Current reactor sizes, for instance, mean that even a large wind farm could only provide enough energy to convert CO_2 to fuel six aircraft, while airlines like Lufthansa operate over 700 planes daily. Fleischer emphasized that in Solar-to-X, scale is critical. Achieving success requires balancing cost, reliability, and sustainability, all of which depend on comprehensive techno-economic studies before implementation.

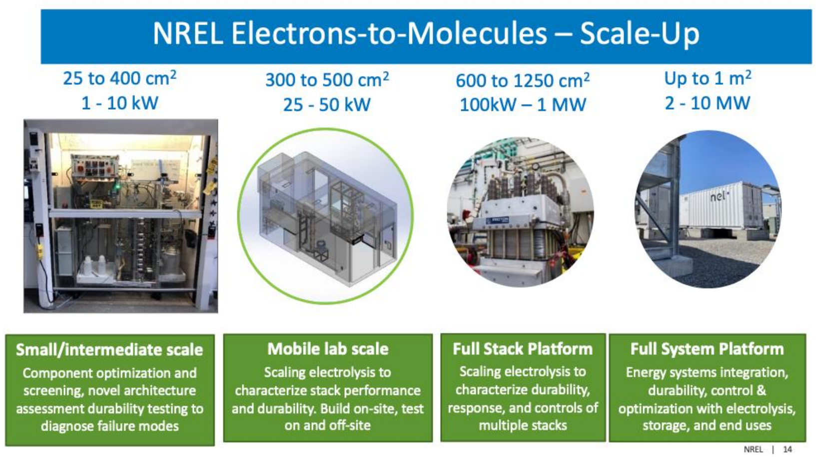
- **Eric De Coninck** (ArcelorMittal). Policy changes are crucial for achieving climate neutrality. While large-scale projects are emerging in Europe, carbon capture and utilization (CCU) is already commercial in other regions. In China, for instance, plants are converting carbon dioxide into methanol, ethanol, and other renewable fuels and chemicals. In contrast, Europe's CCU technology is largely in the pilot phase, likely due to stringent regulatory demands on energy use and greenhouse gas reduction. Biofuels also face challenges due to legislation limiting the biomass used. Revising EU policies could accelerate the development of Solar-to-X, Power-to-X, and CCU technologies, aligning Europe with advancements seen elsewhere.



- **Dennis Krämer** (DECHEMA). A presentation on a techno-economic study by the German Ministry of Research and Education followed, assessing the impact of artificial photosynthesis technologies (and available on www.co2-utilization.net). The study evaluated the economic and environmental benefits and identified key issues: stability and durability challenges must be addressed before commercialization. Disruptive innovations are needed to advance from today's TRL 3-4 to market readiness. However, the study remains optimistic, citing the rapid advancements in photovoltaics as a potential model. If successful, artificial photosynthesis could make green hydrogen cheaper than grey hydrogen, meeting or surpassing the €3 per kilogram target. Success hinges on open data, common standards, and collaboration, drawing lessons from international projects like the Human Genome Project. Multidisciplinary efforts and robust networking will be crucial for developing scalable, durable systems.

- **Francesca M. Toma** (Helmholtz-Zentrum Hereon and Lawrence Berkeley National Laboratory). Based on her research experience in the U.S., Francesca depicted parts of the U.S. strategy on solar fuels. The US, for example, promotes ambitious long-term projects with strong funding, such as reducing green hydrogen to $1 per kilogram. The HydroGEN project, involving five National Research Laboratories, has received $62 million since 2016.[11] These labs collaborate on manufacturing, testing, and modeling and have published some promising results in photo-electrocatalytic systems, reproduced across the country. Some systems have exhibited over 5% solar to hydrogen efficiency with a stability of approximately 80 hours. Overall, the strategy aims to achieve circularity and sustainability, not only towards more sustainable fuels, but also in the production of key chemical feedstocks such as ammonia and urea.

- **Bill Tumas** (National Renewable Energy Laboratory). Hydrogen – and clean synthetic fuels – can find inspiration in the field of photovoltaics, which achieved over 100-fold reduction in cost in 40 years. Similarly, policymakers can also facilitate the adoption of green or or alternative fuels and products to put Solar-to-X on the pathway to viable commercial technologies before 2035. While electrolytic hydrogen production is critical a more holistic view should also encompass more than water splitting and consider concepts such as the manufacturing of chemical feedstocks, the production of food, reactive DAC and CCU concepts, and exploring the possibilities of electrochemistry in oxidation reactions (e.g. anode reactions).



Collaboration will be key to achieve success in Solar-to-X. The EU, the U.S. and the broader international community can create an ecosystem of cooperation to catalyze innovation and coordinate efforts towards sustainability. Key areas for collaboration could include ensuring a faster assessment of standards, benchmarks, and KPIs, which we have established play a key role in creating a global understanding of the challenges and opportunities and facilitate industry uptake. Such an approach should be multidisciplinary, creating interactions across fields

[11] As a reference, the EIC has invested €70 million in "clean energy" challenges since 2020, including Green Hydrogen, CO_2 valorisation and, now, Solar-to-X technologies.

(chemistry, materials science, engineering, social sciences, economics) and stakeholders, taking into account the view from academics, industry leaders and policymakers, as well as fostering an entrepreneurial environment to promote ground-breaking ideas and innovations.

10. CONCLUSIONS

The EIC event, "Harnessing Renewables for a Sustainable Future," held in Genk, Belgium, brought together over 130 participants from academia, industry, policy, and finance to explore the future of Solar-to-X technologies. Hosted in collaboration with EnergyVille, imec, the EuroTech Universities Alliance, SUNERGY, and several EU-funded projects, the event fostered dialogue and collaboration across sectors.

Key discussions emphasized the scale of the challenges ahead and the importance of starting to speak a common language within the diverse innovation eco-system of solar-to-X technologies. Common standards, benchmarks, and shared concepts such as TRL, MRL, and holistic techno-sustainability were recognized as critical facilitators for innovation, provided they are developed within an open and participative ecosystem.

Presentations provided a comprehensive overview of the latest advancements in Solar-to-X, Power-to-X, and CCU technologies, while also highlighting industrial needs, including stable legislation. Innovative project pitches further showcased cutting-edge research in sustainability.

In creating an open, collaborative environment for the exchange of ideas, the event catalyzed connections between partners and decision-makers, laying the foundation for future projects and partnerships.

11. PANELISTS AND SPEAKERS

Speakers and panelists with EIC funding

Philipp Engelkamp (Ineratec)
EIC Accelerator ImPower2X
Website · CORDIS

Csaba Janáky (eChemicles)
EIC Ambassador and Transition
SolarCO_2Value
Website · CORDIS

Nicolas Pluméré and
Agarwala Hemlata (TUM)
EIC Pathfinder ECOMO· CORDIS

Pau Farràs (Galway University)
EIC Ambassador and Pathfinder ANEMEL
Website · CORDIS

Rachel Armstrong (KU Leuven)
EIC Ambassador and Pathfinder Mi-Hy
Website · CORDIS

Iker Aguirrezabal (Univ. Basque Country)
EIC Pathfinder CATART
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Gill Scheltjens (D-CRBN)
EIC Accelerator D-CRBN
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Short biographies of invited speakers and panelists:

Joachim John (imec)

Joachim John received his diploma degree in physics at the Albert-Ludwigs-University in Freiburg in 1993 and his Ph.D. in physics at the Federal Institute of Technology (ETH) in Zurich in 1997. In 1998 he joined the Interuniversity Micro Electronic Centre (imec) in Leuven, Belgium, where he is presently Sr. Project Manager in the Energy Department. Since 2021, Joachim John is co-organizer of the e-MRS Fall Symposium "Advanced catalytic materials for (photo)electrochemical energy conversion" in the Program “Materials for Energy". In 2014, he was awarded with the Otto-von-Guericke medal of the University of Magdeburg by minister-president of Saxony-Anhalt Dr. Reiner Haseloff. He published more than 250 papers, gave more than 40 invited presentations, and holds 5 patents. His h-index is 25 with more than 2100 citations of his work.

Carina Faber (European Innovation Council)

Carina Faber has a background in computational materials science, with a PhD in Theoretical Physics from CNRS/CEA/ University Joseph Fourier of Grenoble. From 2020-22, she co-leads a 2-years R&I program on e-fuels for ENGIE. In 2019, during a post-doctoral fellowship at UCLouvain, she leads the development of a technological roadmap on artificial photosynthesis within the EU large-scale initiative SUNRISE. In her current position as Programme Manager at the European Innovation Council, she works on alternative fuels and chemicals made from renewable energy. The considered technologies are diverse, ranging from mature electricity-based to emerging sunlight-driven approaches based on synthetic biology and artificial photosynthesis. To enable a fully circular and sustainable economy, her work also comprises the valorisation of alternative resources, such as wastewater, brines or plastic waste.

Vera Grimm (German Federal Ministry of Research and Education)

Vera Grimm studied chemistry at the Universities of Cologne and Heidelberg and received her PhD in bioinformatics from the University of Cologne in 2003. During her postdoc at the Center of Excellence in Bioinformatics, Buffalo, NY, she worked with Jeff Skolnick on the protein-protein docking problem. She then worked for six years as a Senior Technology Consultant in Foresight at VDI Technologiezentrum GmbH and subsequently for five years at Projekttraeger Juelich / Forschungszentrum GmbH, most recently as Deputy Head of Unit. Her work focussed on identifying future technologies in the fields of biotechnology, bioeconomy, life sciences and renewable energies as well as developing strategies. In 2017, she moved to the German Federal Ministry of Education and Research (BMBF), where she is responsible for the design and implementation of R&I funding programmes.

Fabien Ramos (European Commission, DG CLIMA)

Fabien Ramos is a policy officer at the European Commission. With a decade of experience in climate policies, he plays a leading role in the European Commission's work on Sustainable Carbon Cycles, Industrial Carbon Management, and Carbon Removals policies. Fabien holds a PhD in Geosciences and enjoys gravel cycling in his free time.

Minerva Elias Franquesa (EIB Institute)

Minerva Elias works at the European Investment Bank Institute (EIB Institute) supporting the Dean on the new EIB Institute’s strategy and is responsible for the development of innovation impact programmes portfolio, at the intersection of philanthropy, ecosystem development, and thought leadership. For the past years, Minerva has been a driving force at the European Investment Fund (EIF), where she led InvestEU equity products supporting SMEs and played a pivotal role in shaping thematic investments such as BlueInvest (Blue Economy), Cassini (Space), and EUDIS (Defence). She graduated from the Universitat Autònoma de Barcelona with a degree in Biology and Postgraduate degree in Forensic Sciences and holds an Executive MBA from Solvay Brussels School of Economics & Management.

Philippe Schild (European Commission, DG RTD)

Philippe Schild is a senior expert in the unit responsible for clean energy transitions in the directorate general for research and innovation of the European Commission. He obtained his PhD in plasma physics at the University Joseph Fourier in Grenoble (France) in 1989. He started his carrier as a scientist at the European fusion tokamak experiment, the Joint European Torus (JET). He joined the Directorate General Research and Innovation in 1998, when he started working in the areas of renewable energy technologies. He is contributing to the development of the EU research work programme, to the selection of research projects and their monitoring. His expertise covers the areas of concentrated solar power, photovoltaics, ocean energy and bioenergy. He is now following emerging energy technologies such as solar conversion from artificial photosynthesis. He has been involved in international cooperation from the early time of his carrier. He represented the European Commission in different Technology Collaboration Programmes (TCP) of the International Energy Agency (IEA). He is a co-lead of the Innovation Community "Sunlight to X" of in Mission Innovation. He is also co-leading the development of a research collaboration programme between the EU and Africa in the area of renewable energy under the framework of Climate Change and Sustainable Energy (CCSE) partnership created under the EU-AU (African Union) High Level Policy Dialogue on Science, Technology and Innovation.

Hannah Johnson (Toyota Motor Europe)

Hannah Johnson is a Senior Engineer in the Materials Engineering department at Toyota Motor Europe focussing on research the production of green fuels since 2017. She completed her PhD on green hydrogen production in the Laboratory for Molecular Engineering of Optoelectronic Nanomaterials in École polytechnique fédérale de Lausanne. Her research focusses on hydrogen production and CO2 conversion through (photo)electrochemical and photocatalytic methods. She is coordinator of the Sun-To-X and PH2OTOGEN projects, which focus on solar hydrogen generation.

Philipp Engelkamp (INERATEC)

Philipp Engelkamp is managing director and co-founder of INERATEC, a pioneer in the production of sustainable e-Fuels an e-chemicals from CO2 and hydrogen.
The company uses modular Power-to-X plants to boost the availability of sustainable fuels, enabling the shift from fossil fuels into the next era of mobility. Philipp leads the business development and the sales department of INERATEC. He presents INERATEC as a Top Innovator in SAF selected by the World Economic Forum, to drive the sustainable transformation of the aviation sector.

Sylvain Cros (Institut Polytechnique de Paris)

Sylvain Cros holds a PhD in Energy from Mines Paris-PSL. He began his career as a researcher in satellite image processing for climate modeling, working at both INRAe and École Polytechnique. From 2013 to 2019, he served as the scientific director of Reuniwatt, a French renewable energy startup. In 2019, he joined the Institut Polytechnique de Paris, where he currently leads the solar resource research action of the Energy4Climate center. Additionally, he works as a consultant in weather and climate science for energy systems.

Deepak Pant (VITO)

Deepak Pant is a senior scientist at Flemish Institute for Technological Research (VITO), Belgium working on electrosynthesis and resource recovery, specifically, design and optimization of electrochemical systems for CO2 conversion and microbial electrosynthesis. He has a PhD in environmental biotechnology and has published over 200 papers, 7 books, 6 patents and 40 book chapters. He is Editor of Journal of Environmental Chemical Engineering (JECE) and Bioresource Technology Reports and Editorial board member of Bioresource Technology, ACS Sustainable Chemistry & Engineering, iScience, World Journal of Microbiology & Biotechnology.

Nicola Armaroli (Italian National Research Council)

Nicola Armaroli is a research director at the National Research Council (CNR) in Bologna and a member of the Italian National Academy of Sciences. His research concerns molecules and materials for solar energy conversion and the study of the energy transition to more sustainable models and technologies, also in relation to resource scarcity and climate change. He has published over 250 scientific papers and 12 books. He serves as consultant on energy and resources for international institutions and companies and has given tens of invited lectures worldwide. He has received several scientific awards and is committed to advise people that science and technology – alone – cannot warrant us a sustainable future.

Nicolas Pluméré (Technical University of Munich)

Nicolas Plumeré is professor for Electrobiotechnology at TU Munich. His group focusses on interfacing photosynthetic systems and hydrogenases with electrodes for energy applications. Their expertise includes electrochemistry, polymer chemistry and kinetic modeling. They pioneered bioelectrocatalytic systems for H2 production in an ERC StG and an ERC CoG and now scale hydrogenase and CO2 reducing systems in an EIC (ECOMO) and Horizon Europe funded projects (CirculH2).

Virgil Andrei (University of Cambridge)

Virgil Andrei was born in Bucharest, Romania. He obtained his Bachelor and Master of Science degrees in chemistry from Humboldt-Universität zu Berlin, where he studied thermoelectric polymer pastes and films in the group of Prof. Klaus Rademann (2014–2016). He then pursued a Ph.D. in chemistry at the University of Cambridge (2016–2020), where he developed perovskite-based artificial leaves in the group of Prof. Erwin Reisner, working closely with the optoelectronics group of Prof. Richard Friend at the Cavendish Laboratory. He was a visiting Winton Fellow in the group of Prof. Peidong Yang at the University of California, Berkeley, and is currently a Title A Research Fellow at St. John’s College, Cambridge. His work places a strong focus on material design and practical applications, introducing modern fabrication techniques towards low-cost, large-scale solar fuel production. He was part of the Cambridge team which reached the final of the EIC Horizon Prize "Fuel From the Sun" (European Commission).

Pau Farràs (University of Galway)

Pau Farràs is an Associate Professor in Inorganic Chemistry at the University of Galway. He received his BSc in Chemical Engineering from the Autonomous University of Barcelona and obtained the PhD in Chemistry from the Materials Science Institute of Barcelona.

Muriel Matheron (CEA)

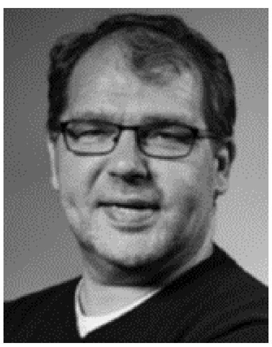
Muriel Matheron obtained her PhD in Material Science in 2005. She is currently Research Director at CEA in the field of CCU, Power, Biomass and Waste-to-X, and Solar-to-X processes. She also has a background in photovoltaic devices, including organic solar cells and silicon / perovskite tandem solar cells, assessing their lifetime and their degradation modes.

Ennio Capria (European Synchroton Radiation Facility)

Ennio Capria is the Deputy Head of Business Development at the ESRF. In his research career he worked on the development of electrochemical nanobiosensors, nano-composites and optoelectronic devices and particularly their characterisation with synchrotron light. At the ESRF, he is coordinating the participation of the ESRF in various collaborative initiative with industry, in particular on energy storage applications, additive manufacturing methods and nano-sciences. Since 2020 Ennio is Director of the Platform of Advanced Characterisation of the Technological Research Institute Nanoelec.

Miet Van Diel (VITO)

Miet Van Dael holds a doctoral degree in applied economic sciences (2014) and master's degree in business engineering (economics) with the option of technology, innovation and environmental management (2010). Currently she works as a researcher at VITO (Belgium) in the unit of Materials & Chemistry (MATCH). Furthermore, she is a guest professor in the environmental economics group at the Hasselt University (Belgium) where she teaches on sustainability assessments for emerging technologies. In her PhD she elaborated on the techno-economic assessment of energy conversion parks and now applies it in the field of a.o. the biobased economy, CCU and plastics recycling. In her research she is further extending the techno-economic assessment to a full sustainability assessment including environmental and social impacts.



Tom Aernouts (imec-IMMOMEC)

Tom Aernouts, R&D Manager Thin-Film PV Technology at imec-imomec, initiated the research on thin film solar cells at imec in 1999. Since 2006, Dr. Aernouts is group leader of imec's Thin Film PV group. Under his impulse, the group has extended its activity in 2014 with the work on hybrid, perovskite-based thin-film solar cells. Since October 2021, Dr. Aernouts leads the merger of thin-film PV activities at imec and imomec, extending the photovoltaics activity into CIGS, Kesterites and other novel material systems. Additionally, solar fuel generation is being explored in his team since that time. Dr. Aernouts received his M.Sc. in semiconductor physics from the Katholieke Universiteit Leuven, Belgium, in 1998, and a Ph.D. in Science in 2006 from the same university.

Laura Torrente Murciano (University of Cambridge)

Laura Torrente is a full professor in Chemical Engineering at the University of Cambridge. Over the last 15 years, her group has been developing sustainable chemical technologies combining areas of catalysis, reactor design and process integration. She is the recipient of an ERC Consolidator grant on green ammonia, working on ammonia synthesis, cracking, safe storage and optimisation of Power-to-X processes.

Francesco Matteucci (European Innovation Council)

Francesco Matteucci is an innovation manager with 20 years of experience spent as a researcher in materials science, as a Corporate R&D Manager within the field of technologies for renewable energy production and storage, and as an intermediary of knowledge trying to exploit the research results within the field of energy and environment. As R&D Corporate manager, he also cofounded and directed several start-ups and joint-labs managing public-private partnerships. As a facilitator of knowledge exploitation (IoK), he co-managed publicly funded projects, as well as Emilia Romagna Climate-KIC Innovation Centre, Dhitech Living Lab on Nano-technologies, Emilia-Romagna Greentech Clust-ER. Francesco acted as scientific expert within the Vanguard Initiative ADMA Pilot, reviewer of research projects, co-authored over 40 scientific papers, 5 patents, and was Visiting Professor at the University of Ferrara as well as speakers in many conferences and workshops. Since October 2020 he is Programme Manager on Advanced Materials for energy and Environmental Sustainability within the European Commission at the European Innovation Council.

Ekke Van Vliet (European Innovation Council)

Ekke has fulfilled various financial roles in the European Institutions in the last two decades. Since 2019, Ekke has been involved in the set-up and implementation of the EIC Fund, the 4-billion EU VC fund, and supporting deep tech start-ups in business development focussing on connections with co-investors and corporates.

Lipsa Nag (Marble Studio)

Lipsa is a Senior Associate at Marble, a leading climate tech venture studio in Paris, where she specializes in identifying emerging sectors and guiding scientists through their entrepreneurial journey. Her strategic insights and hands-on support have propelled six startups from initial ideation to successful venture funding.

Guus Keder (Fenix Ventures)

Guus studied electrical engineering at Eindhoven Technical University, Management at Rotterdam University, and obtained an MBA from INSEAD. During his career, he has mostly dealt with technology-based high-growth entities, in the roles of corporate manager, venture capitalist, entrepreneur, business angel and board member. He is currently involved in research related to the better functioning of the innovation and startup ecosystem, is Chairman of two technology companies and occasionally serves as a jury member for the European Innovation Council.

Rachel Armstrong (KU Leuven)

Rachel Armstrong is a professor of Design-Driven Construction for Regenerative Architecture at the Department of Architecture | Faculty of Architecture, at KU Leuven. She applies biological and origin of life principles to material practices that advance the next generation of sustainable interventions that can unite both the mineral and organic realms to generate positive environmental impacts. She is an EIC Ambassador and coordinator for the Microbial Hydroponics project within the Carbon Dioxide and Nitrogen Management and Valorisation EIC Pathfinder Challenges Portfolio. She also coordinated the H2020 FET Open Living Architecture project that sequenced bioreactors to form a circular domestic utilities system and the Active Living Infrastructure: Controlled Environment (ALICE) prototype that generated an animated interactive biodigital interface and interface to inform the public and introduce the concept of using live microbes as waste processors within our homes and cities.

Iker Aguirrezabal (University of Basque Country)

Iker Aguirrezabal Telleria studied Chemical Engineering at Univ. of Basque Country (Spain, 2006) and did the MSc. in Chemical Engineering at the Univ. of Groningen (The Netherlands, 2009). In April 2014 he started a three-year postdoc period under the supervision of Prof. Iglesia at University of California Berkeley (USA) on structured solids for olefin catalysis. In April 2017 he returned back as Assistant Professor to the University of the Basque Country to work on scaling-up of olefin dimerization under stable Ni-site conditions. In April 2020 he obtained an Associate Professor position in the Chemical and Environmental Engineering Department in Bilbao, Spain. Research tasks involve various chemical engineering processes related to CO_2/H_2O photocatalysis, renewable alcohol production and conversion into sustainable aviation fuels coordinating two European Projects (EIC-Pathfinder and MSCA Doctoral Networks), as participant in one CL5 projects and leader of two national research projects.

Joanna Kargul (CENT, Warsaw University)

Joanna Kargul is a professor at the University of Warsaw and head of the Solar Fuels Laboratory at the Centre of New Technologies. The interdisciplinary work of her group focuses on the rational design and construction of biomolecular artificial photosynthesis systems for renewable chemicals production. In parallel, her group dissects the molecular basis of adaptation of extremophilic microalgae to harsh environmental conditions (e.g., high concentrations of heavy metals and high salinity). Among her many scientific and consulting roles, she is a member of the SUNERGY/SUNER-C Executive Board.

Frédéric Chandezon (CEA)

Frédéric Chandezon, Dr. Ing. Hab. holds an engineer degree in physics (1991) from the Physics and Chemistry school of Paris (ESPCI) and a Ph.D. degree from Grenoble University (1994). After a postdoctoral stay at the Niels Bohr Institute in Copenhagen, he joined CEA in Grenoble as research scientist (1996). He is currently European policy officer for SUNERGY and renewable energy programmes at the Interdisciplinary Research Institute of Grenoble (IRIG) at CEA. Before that, he headed the SyMMES laboratory, a CEA-CNRS-Grenoble University joint laboratory that develops basic research related to low-carbon energy and health. From 2013-2020, he was the coordinator of the EERA Joint Program AMPEA (Advanced Materials and Processes for Energy Applications). Since 2019, he is deputy coordinator of the SUNERGY European initiative on fossil-free fuels and chemicals and of the SUNER-C European project (06/2022 - 05/2025).

Han Huynh (ENGIE)

Developing her practical expertise in carbon capture since 2009, Han Huynh has worked on key projects such as the Nijmegen carbon capture pilot project and the ROAD CCS demonstration project where she was involved in technology assessment, design review, and supplier selection. She has also monitored and conducted pilot testing in carbon capture performance, solvent degradation, and emission risk. Since 2018, Han has coordinated R&D activities on CCU and CCS at ENGIE and became CO2 Domain Manager at Laborelec in 2021. In this role, she supports the ENGIE group and its industrial customers in understanding the role of CCUS in their businesses and mobilizes expert teams for research issues or to give technical support in CCUS de-risking.

Michael Eikerling (Forschungszentrum Jülich)

Michael Eikerling, an expert for physical theory, modeling and simulation in electrochemistry, is Professor at RWTH Aachen University and Director of the Institute of Energy and Climate Research in Forschungszentrum Jülich, Germany (since 2019). He is the scientific coordinator of the Centre for Advanced Simulation and Analytics (CASA, est. in 2021) in Jülich and has co-created the German-Canadian Materials Acceleration Centre (GC-MAC). Research at his institute integrates analytical theory and physical-mathematical modeling with quantum mechanical and classical simulations, striving to unravel the local reaction environment at interfaces, understand transport-reaction coupling in nanoporous media, decipher electrocatalytic reactions, and rationalize the structure vs. property and performance relations of complex electrodes in electrochemical devices.

Csaba Janáky (Echemicles)

Csaba Janáky graduated as a chemist and economist at the University of Szeged, and was a Marie Curie a fellow at the UT Arlington (USA). With his research group he has published over 100 papers (full IF>10 00), filed over 20 patent applications (many of them have already been granted) in the last 10 years. His team has achieved breakthrough results in the development of electrochemical hydrogen generators and in the development of carbon dioxide electrolyzers. He is co-founder of eChemicles, a company where they are scaling-up CO_2 electrolysis.

Moritz Schreiber (TotalEnergies)

Moritz Schreiber is team lead for electrochemical CO_2 conversion to fuels and chemicals at TotalEnergies' R&D. Before, he technically supported the start-up of TotalEnergies first bio refinery for sustainable aviation fuel production. He graduated from the Technical University of Munich and Chimie Paristech and obtained his PhD in heterogeneous catalysis supervised by Professor Johannes Lercher at the Technical University of Munich.

Ifan Stephens (Imperial College London)

Ifan Stephens is a Professor in Electrochemistry at the Department of Materials at Imperial College London. His group's research aims to enable the large-scale electrochemical conversion of renewable energy to fuels and valuable chemicals and vice versa via improved catalysis. Ifan has published >95 papers on topics including oxygen reduction, lithium-ion battery degradation, biomass electro-valorisation, oxygen evolution, CO_2 reduction and nitrogen reduction. Stephens is the recipient of several awards including the Peabody Visiting Associate Professorship from Massachusetts Institute of Technology (2015), European Research Council Consolidator Grant (2021), the Royal Society of Chemistry's John Jeyes Award for his work on hydrogen peroxide production (2021) and the Clarivate Highly Cited Researcher list (2022 and 2023). Ifan's research on H_2O_2 electrosynthesis led to the establishment of the spinout HPNow, which he co-founded; it has raised over €30 million in funding and now sells electrolysers in 15 countries.

Luis Sanz Tejedor (European Patent Office)

Engineer in Rural Mechanics, Patent examiner and Head of Mechanical Division at the Spanish Patent and Trademark Office for 22 years. Part of the EPO in Brussels and of the Observatory on Patents and Technology with the objective of identifying critical technology developments and generating intelligence from patent data.

Maximilian Fleischer (Siemens Energy)

Maximilian Fleischer studied technical physics and received the PhD of TU-Munich, his habilitation and honorary professorship from the TU-Budapest and is member of the Hungarian Academy of Science. He is serving as the Chief Technical Expert of Siemens-Energy in the Corporate Innovation department, reporting to the board member for Corporate Functions, providing guidance on science and technology, and driving innovation. He engages in various industrial boards of Max Plank, Fraunhofer and Helmholtz Institutes, CEC projects, and the US “Liquid Sunlight Alliance” as well as in the pan-European initiative for a cyclic economy “SUNERGY”. He published about 340 times, H-index of 42 and is co-inventor in 180 international patent families.

Eric De Coninck (ArcelorMittal)

Eric De Coninck, graduated in civil engineering at the State University of Gent (1977-1982) After a job as a Researcher in the lab of a paper mill, he joined steelmaking, currently ArcelorMittal Gent. Eric worked as a maintenance manager in the rolling mills, as a production manager in the steel plant, and project engineer at the engineering department. He held different management positions in AM’s affiliations (Bremen), the Liège plant and the Fos sur Mer steel mill, nowadays he is a Project manager at the AM Group CTO Technology Development team, in charge of all aspects of decarbonation.

Bill Tumas (National Renewable Energy Laboratory)

Tumas has been actively engaged in collaborative research and a range of technical management and leadership positions for over 30 years in industry and at national laboratories. He joined NREL in December 2009 as director of the Chemical and Materials Science Center. He has led a number of program development activities and created a number of multi-institution and international collaborations. He has also led two Energy Frontier Research Centers on materials discovery: the Center for Next Generation of Materials Design and the Center for Inverse Design. Prior to NREL, Bill was at Los Alamos National Laboratory for 17 years, where his last position was program director for Applied Energy Programs (DOE's Energy Efficiency and Renewable Energy, Fossil Energy, and Electricity Delivery and Energy Reliability offices). His research activities include materials design, catalysis, supercritical fluids, green chemistry, and waste treatment technology development and assessment. He has over 65 peer-reviewed publications and 12 patents and has given over 125 invited presentations. He is a fellow of the American Association for the Advancement of Science and serves on several advisory boards for energy-related research. He has contributed to several Basic Energy Sciences reports, including as chair for the Roundtable on Liquid Solar Fuels.[12]

[12] Adapted from "William Tumas: Associate Laboratory Director, Materials, Chemical, and Computational Science", NREL. Accessed on 30 September 2024.

Dennis Krämer (DECHEMA)

Dennis is a Senior Advisor in Carbon Management. Since 2010, he has coordinated the scientific support projects of the BMBF funding measures on CO_2 utilization on behalf of DECHEMA. These include, among others, from 2010 to 2016 the measure "Technologies for sustainability and climate protection Chemical processes and use of CO_2", from 2016 to 2019 "CO_2Plus: Material use of CO_2 to broaden the raw material base" and since 2020 "CO_2-WIN: CO_2 as a sustainable source of carbon, pathways to industrial application". Since November 2023, he is also coordination the BMBF-project MyWay. It is the scientific support project of the funding measure SINATRA. The goal of junior research groups here is to discover innovations in the field of artificial photosynthesis and the use of novel materials for hydrogen production. Dennis is an environmental engineer by training, and received his Diploma thesis at the National Center of Atmospheric Research in Boulder, Colorado (United States).

Francesca M. Toma (Helmholtz-Zentrum Hereon)

Francesca M. Toma is the Director of the Institute of Functional Materials for Sustainability at Helmholtz Zentrum Hereon, Germany, and a Distinguished Helmholtz Professor at Helmut Schmidt University in Hamburg. Her research centers on the synthesis and characterization of sustainable materials for renewable energy and biological applications. She also holds a position as a Visiting Professor at Lawrence Berkeley National Laboratory, where she was a Staff Scientist for nearly a decade. She served as the Program lead of the Liquid Sunlight Alliance and as the Photoelectrochemistry Technology Lead for HydroGEN there. In 2022, she also served for a year as a Detailee in the Catalysis Science Program of the Basic Energy Science of the Department of Energy.

Full list of speakers and panelists:

- Maximilian Fleischer (Siemens Energy)
- Nicola Armaroli (CNR - Italian National Research Council)
- Lipsa Nag (Marble Studio)
- Fabien Ramos (European Commission, DG CLIMA)
- Philippe Schild (European Commission, DG RTD)
- Vera Grimm (German Federal Ministry of Education and Research)
- Minerva Elias Franquesa (European Investment Bank Institute)
- Carina Faber (European Innovation Council)
- Francesco Matteucci (European Innovation Council)
- Ekke Van Vliet (European Innovation Council)
- Dennis Krämer (DECHEMA)
- Hannah Johnson (Toyota Motor Europe)
- Csaba Janáky (Echemicles)
- Philipp Engelkamp (Ineratec GmbH)
- Gill Scheltjens (D-CRBN)
- Ennio Capria (European Synchroton Radiation Facility)
- Miet Van Dael (VITO)
- Tom Aernouts (imec-IMMOMEC)
- Eric De Coninck (ArcelorMittal)
- Bill Tumas (National Renewable Energy Laboratory)
- Moritz Schreiber (TotalEnergies)
- Ifan Stephens (Imperial College London)
- Luis Sanz Tejedor (European Patent Office)
- Nicolas Pluméré (Technical University of Munich)
- Pau Farras (University of Galway)
- Rachel Armstrong (KU Leuven)
- Iker Aguirrezabal (University of Basque Country)
- Michael Eikerling (Forschungszentrum Jülich)
- Joanna Kargul (CENT, Warsaw University)
- Muriel Matheron (CEA)
- Laura Torrente Murciano (University of Cambridge)
- Francesca M. Toma (Helmholtz-Zentrum Hereon)
- Sylvain Cros (Institut Polytechnique de Paris)

- Deepak Pant (VITO)
- Frédéric Chandezon (CEA)
- Kristof Verbeeck (ArcelorMittal Belgium)
- Guus Keder (Fenix Ventures)
- Virgil Andrei (University of Cambridge)
- Joachim John (IMEC)
- Anne-Marie Sassen (European Innovation Council)
- Han Huynhthi (ENGIE)

ABOUT THE REPORT

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