LC-SC3-RES-1-2019-2020
Developing the next generation of renewable energy technologies

CONDOR

COmbined suN-Driven Oxidation and CO_2 Reduction for renewable energy storage

Starting date of the project: 01/11/2020
Duration: 48 months

= Deliverable D9.4 =

Stakeholders feedback

Dissemination level		
PU	Public	x
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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Executive Summary

The "*Harnessing Renewables for a Sustainable Future*" workshop, held in Genk, Belgium, on June 4-5, 2024, brought together leaders in the Solar-to-X and renewable energy sectors to explore advancements in sustainable, solar-powered fuel production technologies. Supported by CO_2 Value Europe and hosted by EnergyVille, the event featured pitches from EU-funded projects, including the CONDOR project, which aims to transform CO_2 and water into fuels like Dimethyl Ether (DME) and methanol using sunlight.

Stakeholders, including academics, industry experts, and policymakers, examined the state of Solar-to-X technologies, noting challenges such as regulatory barriers and the need for improved cost-effectiveness. A key takeaway was the importance of aligning Technology Readiness Levels (TRL) with Manufacturing Readiness Levels (MRL) to expedite commercialization. Emphasis was placed on developing sustainability frameworks to assess environmental, social, and economic impacts early in the technology's life cycle.

The CONDOR project, highlighted for its potential to advance Europe's climate neutrality goals, faced significant interest but also scrutiny regarding scalability and financial feasibility. As it progresses through MRL 5 with a working prototype, further validation is needed to solidify its competitive edge in the renewable fuel market.

In summary, the workshop underscored a shared commitment to advancing Solar-to-X technologies, particularly by bridging the gap between research and industry, fostering cross-sectoral partnerships, and ensuring that regulatory and financial support aligns with innovation goals.

Figure 1 Workshop "Harnessing Renewables for a Sustainable Future", June 4-5, Genk, Belgium

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1. Introduction

Deliverable D9.4 "Stakeholders' feedback on the workshop unlocks the barriers to the deployment of CONDOR technology as part of Work Package 9. As a part of this task, an international industry-oriented workshop was held with the support of CO_2 Value Europe to gather relevant stakeholders and experts from the Solar fuel community, e.g. SUNERGY community. The outcome of this workshop is used for presenting an overview of the SWOT analysis.

Information on the workshop:
On 4 and 5 June 2024, the workshop was organized 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 sustainable production of fuels.
- 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.

Figure 2 Material used by all organizers to promote the workshop

2. Outcome of the workshop

2.1 Solar to X: where we are now?

Europe is committed to becoming the first climate-neutral continent, which requires strong collaboration between policymakers and innovators to foster deep-tech solutions. 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.

Nicola Armaroli, from CNR in Italy, presented the perspectives and challenges of this emerging field– particularly the restructuring needed in the energy landscape to adapt to the climate crisis. The importance of adaptation and climate resilience was mentioned. 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.

Figure 3 Keynote speech of Nicola Armaroli

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.

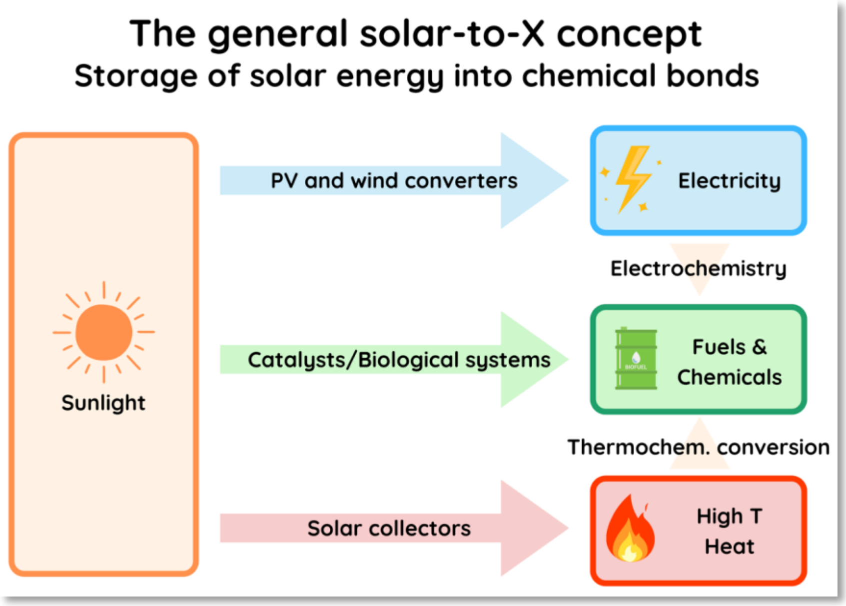


Figure 4 General Solar-to-X concept

This comprises different technological approaches, such as electrochemical, photoelectrochemical or photobiological conversion mechanisms. Harnessing solar energy represents a great opportunity for the European economy.

The average solar energy received on the surface of the EU is 5.5x10^5 kWh per year – yet we only consume a staggering 0.3% of it (1.5x10^13 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.
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.

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.

To this end, the European Innovation Council (EIC) want 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.

All panellists emphasized the importance of collaboration for 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.

2.2 Scaling from Lab to Market: Bridging Technological Maturity with Market Readiness

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.

Miet Van Dael (VITO) 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 standardized evaluation of results. The main goal is to identify the parameters that have the highest impact on the sustainability of solar-to-X technologies. 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.

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?', 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.

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)6 to ensure efficient and sustainable innovation.

MRL, which is more relevant in the phases of commercialization, evaluates how ready a technology is for the market. 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 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 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.

2.3 Navigating the Deep Tech Innovation Path: From Lab Concept to Market

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.

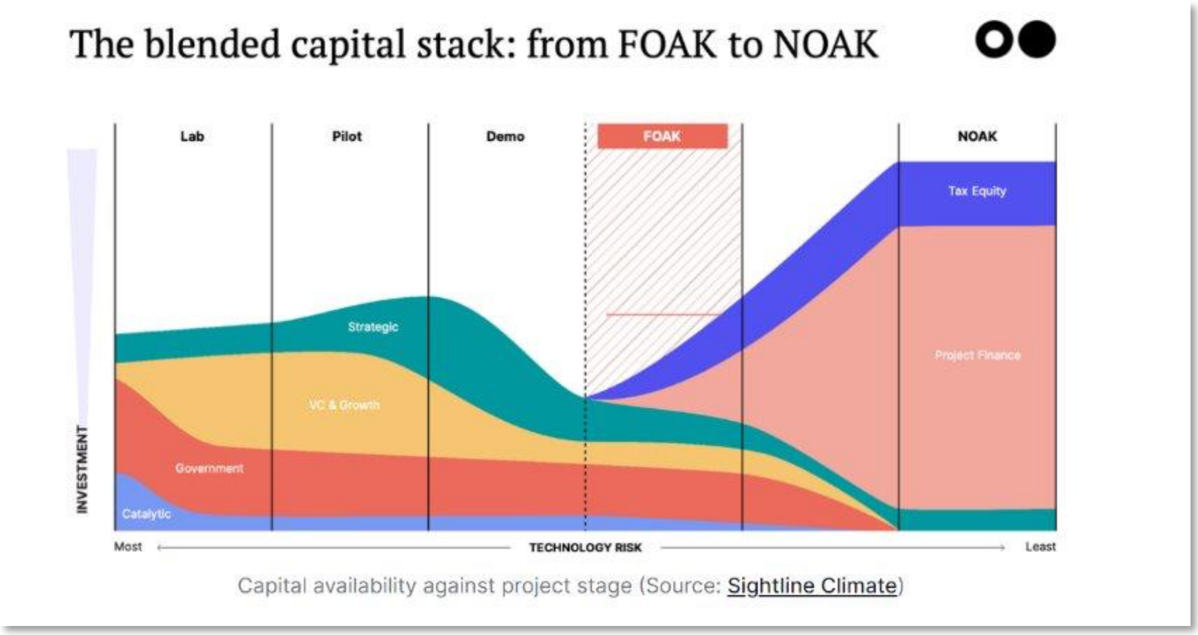


Figure 5 From FOAK to NOAK

The Figure 5 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 7 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 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.

3. The path forward for CONDOR

The CONDOR project specifically aims to develop a modular system that produces fuel from water and carbon dioxide, using directly sunlight as the energy source. This approach effectively stores the intermittent energy from sunlight into high-density energy carriers that can be utilized as needed. The combined expertise allows CONDOR to achieve a technology readiness level (TRL) of 4 for integrated fuel production with high efficiency, setting the stage for industrial-scale fuel production.

During the recent Solar-to-X workshop, the CONDOR project was introduced as a collaborative partner, sharing common goals with other stakeholders in advancing solar-to-fuel technologies. Overall, the response to CONDOR was positive, with stakeholders recognizing its potential as a sustainable, decarbonizing technology. CONDOR was not only acknowledged for its promising role in producing Dimethyl Ether (DME) and methanol but also for its broader application potential. With the integration of additional processes, CONDOR could enable the production of various valuable materials, expanding its scope and impact within the solar-to-X domain.

Despite its potential, CONDOR faces commercialization challenges marked by uncertainties in both technical and market viability. Effective commercialization would require a comprehensive assessment that addresses technical efficiency, scalability, and financial feasibility. The solar-to-X landscape features numerous projects, each leveraging solar energy for various high-value end products. However, common challenges remain across these technologies, including low yields, high capital and operational costs, limited commercial-scale demonstrations, restricted operational windows, and reliance on complex, costly materials and storage solutions. Addressing these issues is essential for viable commercialization.

For CONDOR's successful market introduction, a balanced evaluation of its economic and environmental impact is imperative. Benchmarking CONDOR against other solar-to-X technologies and conventional processes will require thorough techno-economic assessments and detailed plans outlining its scaling roadmap to Manufacturing Readiness Levels (MRL). This dual focus on Technology Readiness Level (TRL) and MRL development is crucial, as misalignment between the two can delay market deployment and hinder technology adoption. Presently, CONDOR is estimated to be at MRL 5, with a working prototype in place.

Moving forward, the next steps for CONDOR include demonstrating a fully operational system, emphasizing its strengths, and showcasing a clear pathway for further improvement and development. These steps will be crucial for attracting additional funding and accelerating CONDOR's journey toward commercial viability and sustainable industrial application.

4. Conclusion

This document represents Stakeholders feedback from the "*Harnessing Renewables for a Sustainable Future*" workshop, held in Genk, Belgium, on June 4-5, 2024. 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 CATART (grant agreement no. 101046836), FlowPhotoChem (grant agreement no. 862453), and EU SUNERGY initiative (grant agreement no. 101058481).

Making sustainable fuels, chemicals and materials solely from renewable energy, water and abundantly available resources is a promising pathway for climate change mitigation. The brought a wide panorama of stakeholders (academics, industrials, policy makers) around the exciting topic of solar fuel. Throughout this event, CONDOR connected with a large community to improve our understanding on the challenges and opportunities for solar fuel in general and CONDOR in particular and so shape the future for this emerging technology.

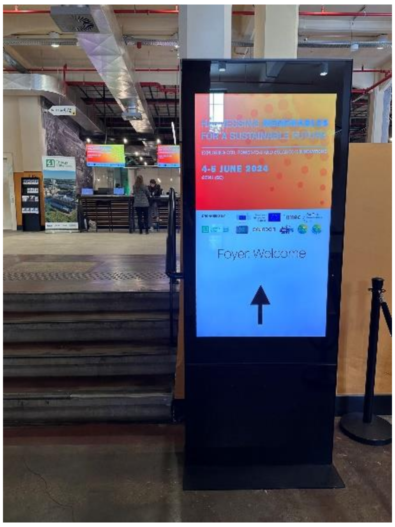
5. Degree of progress

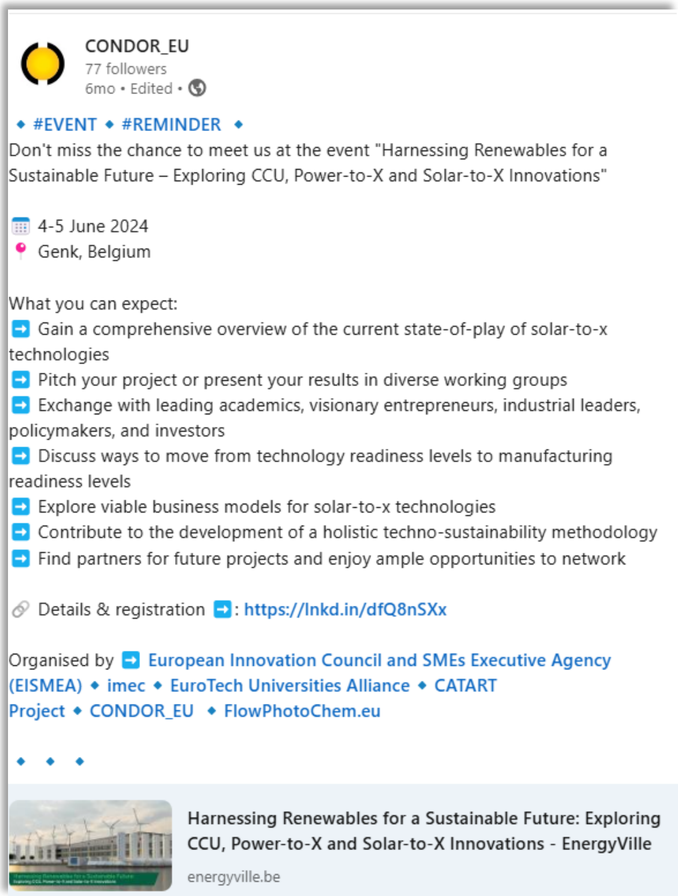
The deliverable is 100% fulfilled and represents the outcomes of the CONDOR clustering event.

6. Dissemination level

The Deliverable D9.4 is public and therefore it will be available to download on the project's website.

Appendix I: Dissemination and photo gallery





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◆ #EVENT ◆ #REMINDER ◆
Don't miss the chance to meet us at the event "Harnessing Renewables for a Sustainable Future – Exploring CCU, Power-to-X and Solar-to-X Innovations"

4-5 June 2024
Genk, Belgium

What you can expect:
➡ Gain a comprehensive overview of the current state-of-play of solar-to-x technologies
➡ Pitch your project or present your results in diverse working groups
➡ Exchange with leading academics, visionary entrepreneurs, industrial leaders, policymakers, and investors
➡ Discuss ways to move from technology readiness levels to manufacturing readiness levels
➡ Explore viable business models for solar-to-x technologies
➡ Contribute to the development of a holistic techno-sustainability methodology
➡ Find partners for future projects and enjoy ample opportunities to network

Details & registration ➡: https://lnkd.in/dfQ8nSXx

Organised by ➡ European Innovation Council and SMEs Executive Agency (EISMEA) ◆ imec ◆ EuroTech Universities Alliance ◆ CATART Project ◆ CONDOR_EU ◆ FlowPhotoChem.eu

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Save the dates!

Join us for the *Harnessing Renewables for a Sustainable Future: Exploring CCU, Power-to-X and Solar-to-X Innovations* organised in collaboration between European Innovation Council and SMEs Executive Agency (EISMEA), EnergyVille, imec, EuroTech Universities Alliance, EU projects CATART Project I CONDOR_EU I FlowPhotoChem.eu I SUNERGY - Fossil-free fuels and chemicals for a climate-neutral Europe

4-5 June 2024
EnergyVille in Genk, Belgium

Topics covered:
• From a societal need to technological innovation: #policy, #industrialization and #investors session
• Solar-to-X devices: where are we now?
• The devices of tomorrow: with #biotechnology, autonomous operation and computational materials science to fully #sustainable devices
• Transition of technology to (social) innovation: techno-sustainability assessment, social challenges and opportunities and market considerations
• Standards, common metrics, fair benchmarking: key enablers for upscaling technology

Next to plenaries and panel #discussions, the programme will include #workshops in parallel sessions and also #demonstrators to showcase European innovations.

Preliminary agenda & Registration: https://lnkd.in/eHN9p5jT

Stay tuned for details!