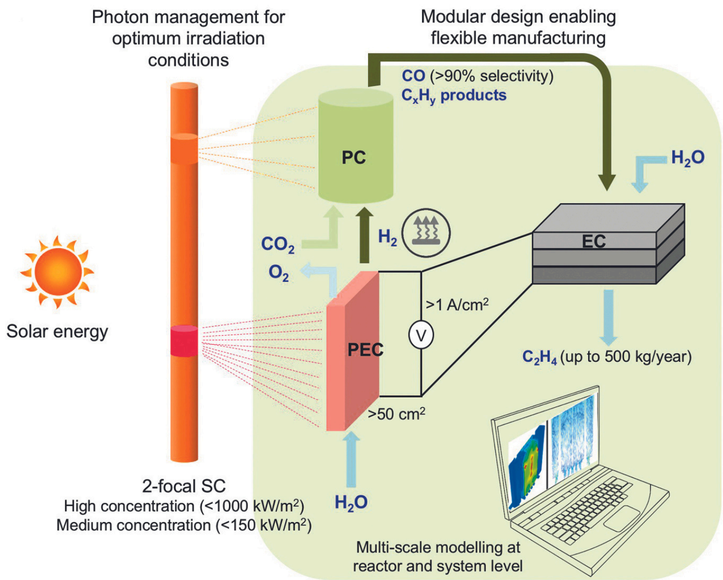
Sustainable Chemicals from Sunlight and Carbon Dioxide

FlowPhotoChem is a multi-national, EU-funded research project developing new and better ways to manufacture chemicals using carbon dioxide and sunlight. Solar energy and advanced catalysts can be used to convert carbon dioxide into fuels and useful chemicals, replacing current fossil fuel-based approaches.

FlowPhotoChem addressed the key challenges to achieving more sustainable chemical manufacturing – more effective solar light management, more efficient reactors, and more durable catalysts. The project assembled many of Europe's leading R&D teams in this and related fields, from computer scientists and modellers to chemists, reactor designers and catalyst companies.

This brochure highlights our partners' main FlowPhotoChem achievements. To learn more about FlowPhotoChem technologies, visit the project website (www.flowphotochem.eu).



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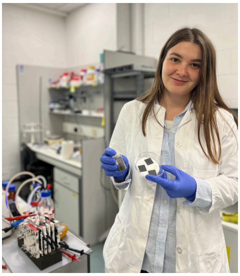
The University of Galway in Ireland coordinated the project, led by Dr Pau Farràs.



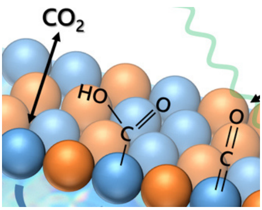
Dr Farràs' research group developed new families of materials that can be used as oxygen evolution reaction (OER) electrocatalysts in alkaline conditions. These materials can be used in photoelectrochemical (PEC) and electrochemical reactors (EC) to provide platinum group metal (PGM)-free alternatives while maintaining suitable activity and stability. In addition, some new photocatalysts for the photochemical reactor (PC) were provided to other project partners showing promising activity toward the targeted reactions.

The economic analysis led by Dr van Rensburg has been extremely useful to support the exploitation of some of the reactors, showing economic benefit to potential investors.

The Swiss Federal Institute of Technology Lausanne (EPFL) was responsible for the PEC reactor, led by Dr Sophia Haussener.

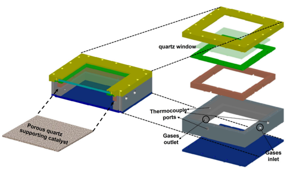
EPFL demonstrated long-term operation and stability of the large-scale PEC flow reactor and the overall system for the generation of solar hydrogen. This demonstration is extremely important for the commercialisation of the system, already underway in partner SoHHytec. EPFL demonstrated the thermally integrated flow reactor concept for the direct reduction of CO_2 to syngas with unprecedented performance, and its scaling to an intermediate scale, both demonstrated in EPFL's high flux solar simulator. The direct conversion of CO_2 to syngas might represent an important step for the production of liquid fuels. Additionally, EPFL was able to model the PEC flow reactor for CO_2 reduction and collaborated to provide a multi-scale simulation framework for the modelling of the detailed electrode-electrolyte interface.

Dr Matt Mayer’s group at the Helmholtz Zentrum Berlin led the development of the EC flow reactor.



At the HZB, a central goal was to develop methods to understand dynamic processes occurring inside the electrochemical reactor during operation, which help to understand things like product selectivity and performance degradation. In joint efforts with eChemicles, we developed an electrolyzer cell with X-ray transparent windows which allows us to study the system using a variety of methods, including X-ray absorption spectroscopy, radiography, and diffraction. These can give detailed insight into cell behaviors and will help guide the development of more selective catalysts and methods for improved stability.

The Instituto de Tecnologia Quimica at Valencia Polytechnic University conducted the work on the flow PC reactor as led by Dr Josep Albero.

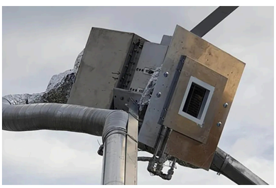


Our participation in FlowPhotoChem has driven significant strides in synthesizing and characterizing photocatalysts, alongside designing, fabricating, and scaling up photoreactors. Collaborating with consortium members ICIQ, eChemicles, University of Amsterdam, and DLR, we've pioneered novel catalysts and reactors, revolutionizing photoassisted CO2 hydrogenation under continuous concentrated sunlight. Leveraging flow photochemistry, we've achieved superior reaction control, selectivity, and stability. Furthermore, we've delved into the intricate mechanisms governing these reactions, pinpointing key limiting steps to push beyond the current state of the art.

The ICIQ ‘s research in the modelling of photo-electro-catalysis was led by Prof. Núria López and her group.

ICIQ's contribution to FlowPhotoChem focused on computational modelling to advance the electrochemical CO_2 reduction catalysts and electrolyte conditions. The promising alloys for ethylene formation were identified through a descriptor approach and uploaded to the open source iochem-BD database. The ab initio multiscale modelling for CO formation was done in collaboration with EPFL to optimize the electrolyte microenvironments for practical cell configurations used in FlowPhotoChem processes. The multiscale methodology and open-sourced datasets will accelerate the development of optimal electrode/electrolyte interfaces for CO_2 reduction reactions.

SoHHytec were involved in the continuous enhancement of the PEC reactor in the FlowPhotoChem system.

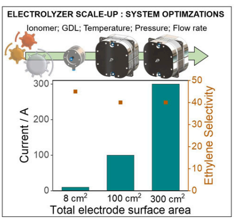


Through our involvement in FlowPhotoChem, we demonstrated the robustness of our reactor through extensive testing under various seasonal conditions, showcasing its reliability. Additionally, we identified areas for improvement and successfully implemented upgrades, particularly enhancing optical and thermal management components, thereby optimizing reactor performance. Furthermore, in collaboration with other systems, we showcased the integration of our reactor to produce sustainable Ethylene, indicating its compatibility and potential for broader applications in renewable energy systems.

MEMBRASENZ, led by CEO Dr Jelena Stojadinovic produced and tested catalysts for FPC's energy conversion systems.

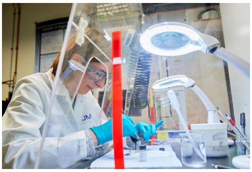
MEMBRASENZ's role in FlowPhotoChem was the development of membranes for PEC and EC reactors. Besides the founder of MEMBRASENZ, Dr Jelena Stojadinovic, who was actively involved in R&D activities, Dr Anna Igual and Dr Vincent Cremet were working on laboratory testing and membrane digital twin generation. Results obtained from membranes' testing at the Helmholtz Zentrum Berlin, University of Szeged and EPFL helped improve the performance. Collaboration with the partners Leitat and Johnson Matthey on Life Cycle Analysis and Techno-economic Analysis enabled the identification of optimal materials and strategies for new products' exploitation.

The University of Szeged designed and developed new methods to refine electrocatalysts in the EC reactor. This work was driven by Profs. Csaba Janáky and Balázs Endrődi.



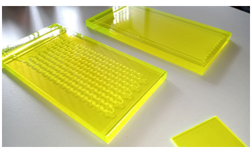
Our team was involved in targeting the electrochemical reduction of carbon monoxide to valuable, multi-carbon products. For this, the electrolysis system, and the analytical methods (NMR, gas chromatography, HPLC) have been upgraded at our university. A new electrolyzer cell type, a microfluidic electrolyzer was designed and manufactured, allowing the rapid testing of new catalysts. Beyond this, CO electrolysis experiments were performed in a 100 cm2 geometric area three-layer electrolyzer stack, on a system that was specifically designed for this purpose (including various safety functions).

Johnson Matthey (JM)'s Drs Gareth Williams and Urša Podbevšek added expertise in advanced material development and helped identify and characterise business opportunities.



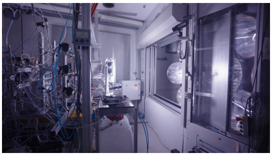
The Johnson Matthey team led the development of the cathode catalysts. Our in-house material development was supported by project partners who tested the performance of the catalysts and electrodes developed at JM. The technical know-how obtained within the project, including catalyst ink and electrode preparation, cell and test stand design, and test conditions, will be used in further technology development. Additionally, exploring the market opportunities for the FlowPhotoChem system gave us a greater understanding of the current landscape of solar fuels and chemicals and related technologies.

The University of Amsterdam developed and optimized FPC's energy-efficient solar photoreactors. Prof. Timothy Noel's team included Drs Stefan Zondag and Tom Masson.



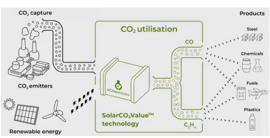
At the University of Amsterdam, we set out to further investigate the potential of luminescent solar concentrators as cheap and potent photochemical reactor designs. As these luminescent reactors can harvest both direct and diffuse sunlight, solar irradiation can be harvested without the need for solar tracking or parabolic collectors. For the first time, replaceable luminescent coatings were introduced in our work, allowing the transformation of any typical glass plate photoreactor into a luminescent one. This provided flexibility in the organic dyes used, allowing tunability of the relevant spectrum for a broader scope of photochemical transformations.

DLR was responsible for the validation and demonstration of the integrated FlowPhotoChem system. Dr Michael Wullenkord orchestrated this work.



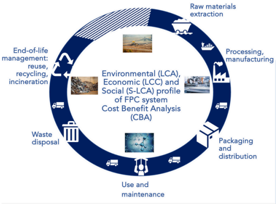
DLR led the modelling, design, optimisation, and experimental assessment of the integrated FlowPhotoChem system, which features a serial arrangement of a photoelectrochemical (PEC), a photocatalytic (PC), and an electrochemical (EC) reactor. The development of the individual reactors was guided from the system's perspective. A system model was created using simplified reactor models. This allowed us to identify ways to improve solar-to-ethylene efficiency and the production rate at the reactor and system levels. Experimental results from the High-Flux Solar Simulator were used to validate and refine system models, which form a valuable basis for the further development of the modular FlowPhotoChem approach.

eChemicles participated in FlowPhotoChem as a reactor designer and scale-up partner. They are involved in system integration and techno-economic evaluation of the integrated FlowPhotoChem system.



Within FPC eChemicles developed a new continuous photoreactor capable of operating in an almost unattached parameter space, up to a temperature of 250 °C, pressure of 50 bar and simulated concentrated solar irradiation up to 5 Sun intensity. This unique photoreactor allows catalyst testing in a wide parameter space. The scale-up activity of electrolysers for CO reduction towards ethylene formation resulted in an approximately 12-fold increase in geometric area in a stackable way resulting in an overall 40-fold increase in conversion capacity. Demonstration of scalability and robustness of the technology is extremely important for industrial utilization.

Leitat Technological Center led the life cycle assessment of the FPC system and assisted in the characterization and evaluation of raw materials and catalysts.



In the research stage, Leitat supplied environmental information supporting the selection of the candidate materials developed by the technological partners (e.g., HER and OER catalysts, membranes). At the demonstration level, environmental hotspots for individual reactors (PEC, PC and EC) and the FPC integrated system compared to conventional technologies have been identified, and recommendations for improvement have been provided. In addition, Leitat contributed to the development of efficient Hydrogen Evolution Reaction (HER) electrocatalysts with earth-abundant metal as an alternative to traditional commercial catalysts based on platinum. Specifically, Leitat synthetized HER catalyst based on Metal-Organic Frameworks (MOFs) containing metal nanoparticles.

Kyambogo University supported FlowPhotoChem's dissemination and exploitation activities in African countries where solar conversion technologies can play a significant role in developing sustainable manufacturing in remote areas. This work was coordinated by Dr Justus Masa.

Scientifically, enhancement of the electrochemistry research facilities has improved graduate training and research, especially, the foundations for electrochemistry research. At the technical level, FlowPhotoChem improved the capabilities of the electrochemistry laboratory and expanded on our potential partners. By this, Kyambogo University is positioning itself as a leading national and regional centre of competence in electrochemistry with a broad international network of potential collaborators and institutions.

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