HORIZON-JTI-CLEANH2-2023-01-04: Photoelectrochemical (PEC) and/or Photocatalytic (PC) production of hydrogen

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of maximum EUR 2.50 million would allow these outcomes to be addressed appropriately.
Indicative budget	The total indicative budget for the topic is EUR 2.50 million.
Type of Action	Research and Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 2-3 and achieve TRL 5 by the end of the project - see General Annex B.

Expected Outcome

Photo(electro)chemical systems have been identified as one of the promising technologies to meet long-term hydrogen-production goals as they integrate the photovoltaic and electrolysis function in a single energy conversion step. Remarkably, the direct use of sunlight to bias the chemical reaction also decouples the hydrogen-production process from power price fluctuations. Together, these provide advantageous prospects for the reduction of both CAPEX and OPEX, especially in geographies with large renewable potential.

From a technological point of view, commercial photo(electro) chemical systems are expected to benefit from simplified Balance-of-Plant (BoP) architectures, enabling a market penetration at both centralised and decentralised level. Additionally, R&D in materials science should aim to discover novel abundant and cost-effective photo(electro) catalyst as well as more integrated process design promises in the photovoltaic, electrolysis and bio-chemical fields.

Project results are expected to contribute to all of the following expected outcomes:

- Development of breakthrough technologies able to harvest the renewable energy source potential in the EU regions and neighbourhoods;
- Strengthening the solar-energy conversion technologies EU value-chain, in terms of both innovation and manufacturing capability;
- Contribute to the demonstration of the first scalable photo(electro)chemical system by 2028;
- Execution of techno-economic analyses and/or technology-transfer scenarios for the simultaneous production of renewable hydrogen and value-added chemicals or biomass/waste reformate obtained from sunlight-driven process.

Project results are expected to contribute to the following objectives and KPIs of the Clean Hydrogen JU SRIA:

- Reducing CAPEX and OPEX, improving the efficiency of processes and scaling up
- For PEC systems, a solar-to-hydrogen conversion efficiency higher than 15% as well as the build-up of a demonstration PEC cell with an active area of at least 500 cm^2. Additionally, the Faraday efficiency should exceed 90 % and the cumulated operation time under natural sunlight should be higher than 500 hours;
- For PC systems, a solar-to-hydrogen conversion efficiency higher than 5% as well as

the build-up of a demonstration PC reactor with an active area of at least 500 cm^2. Additionally, the cumulated operation time under natural sunlight should be higher than 500 hours.

Scope

Photo(electro)chemical systems are expected to play a major role in renewable hydrogen production, aiming to compete on a medium- to long-term basis with commercial systems comprising separated photovoltaic and electrolysis modules. These systems, despite the continuous improvements being achieved at the stack cost, still suffer from expensive BoP units – especially the electrical components – that typically amount to half the system cost. In addition to that, the LCOH is largely determined by price of electricity needed for the electrolysis process. Innovative technologies, complementing the CAPEX and OPEX optimisation efforts infused to electrolysers R&D, are highly sought to accelerate the market competitiveness of renewable hydrogen.

Notably, solar-to-hydrogen (STH) conversion systems such as photovoltaic + electrolysis (PV+EC) have been widely investigated to tackle the aforementioned issues. Similarly, in the PECDEMO[67] project lab-scale hybrid PEC-PV specimens have reached STH efficiencies above 15% (also under concentrated irradiation), active areas greater than 50 cm^2 and stability of 1000 hours, but not in one device. Improvements to such figures-of-merit have been later demonstrated in the PECSYS[68] project, where STH efficiencies soared higher that 20% on small active areas, while few m^2 devices operating with natural sunlight reported efficiencies of 10%. The rich academic literature witnessed up to 30% STH efficiencies for integrated PV+EC devices under concentrated irradiation, yet industrially relevant demonstration of pure PEC or PC is lagging behind with respect to PV+EC devices. The Innovation Fund supported SUN2HY[69] project which aims to demonstrate a pre-commercial plant having STH efficiency >13% at a scale above 1m^2 module with a 70,000-80,000 hours stability. To this extent, strategies to get closer or beyond the Shockley-Queisser limit, especially system design featuring solar concentration, should be pursued for PEC and PC. As a result, specific R&I areas are needed to be tackled to further progress PEC and PC before demonstration in an industrially relevant environment as follows:

- Demonstration of a commercially viable PEC or PC devices, i.e. comprising a single component that integrates both the solar harvesting and catalytic function. Therefore, proposals on PV biased electrolysis or PV biased PEC devices are not in the scope of this topic;
- Novel photo-chemical reactor design, based on flow conditions rather than batch or semi-batch prototypes;
- Integration of solar concentration architectures, featuring photon management concepts through suitable optics and heat removal and usage concepts, or via disruptive nanomaterials design that promote local concentration of the incoming radiation;
- Expansion of the arsenal of materials for efficient solar energy conversion, including semiconductor oxides, selenides, nitrides, halide perovskites, polymers and the

[67] https://cordis.europa.eu/project/id/621252
[68] https://cordis.europa.eu/project/id/735218
[69] https://climate.ec.europa.eu/system/files/2022-07/if_pf_2021_sun2hy_en.pdf

respective hybrids, as well as bio-hybrids enzyme-semiconductors, also leveraging on Z-schemes or multi-junction semiconductor systems. Approaches promoting the use of abundant or easily recoverable materials is encouraged;

- Development of effective passivation strategies to mitigate chemical/electrochemical corrosion of semiconductor photoelectrodes and photocatalysts and thereby improve their operational lifetime;
- Development of cost-effective, scalable processing methods enabling the coupling of efficient hydrogen evolution, oxygen evolution or electro-oxidation (co)catalysts to semiconductor photoelectrodes and photocatalysts;
- Alternative photo-chemical reactions beyond conventional water splitting, de-coupling hydrogen and oxygen production in favour of more economically attractive and/or less energy-demanding oxidative reactions, such as biomass/waste photo-reforming or direct saltwater photo(electro)catalysis

The scope of this topic should therefore address the lack of industrially relevant photo-chemical reactor, offering advantages in terms of land-use, simplified system layouts and lower cost. The use of flow conditions is particularly relevant for PC systems, that are often tested in custom batch-type lab reactors without internationally acknowledged measurements protocol and standards. Consequently, projects are expected to validate novel STH conversion reactors in relevant environments. To this extent, monolithic or highly integrated photochemical devices should be developed, while simple electrical connection between photovoltaic cells and electrolysers or PV biased PEC configurations are not in the scope of this topic.

Furthermore, the scope of this action is to validate novel photo-active materials of at least 5% - for PC – and above 15% - for PEC – STH efficiencies. To achieve such goal, proposals are expected to pursue strategies that aim to improve both light harvesting and catalytic properties, namely core/shell or hybrid nanomaterial synthesis, materials showing plasmonic effects or selective photo(electro)catalyst for alternative oxidative reactions beyond water oxidation.

Overall, proposals should address the following targets at the system level:

- A photo(electro)chemical system with a minimum cumulated hydrogen production of 75 kWh/m^2 for PEC or 25 kWh/m^2 for PC systems, respectively, for the 500 hours of pilot demonstration;
- The concepts used in developing the novel reactor should allow scalability to higher throughput not only by numbering up reactors but also by increasing the single reactor throughput;
- Photo(electro)chemical reactions beyond conventional water splitting may be also demonstrated, in particular hydrogen-producing de-coupled reactions improving state-of-the art demonstration of solar-to-chemical energy conversion;
- A functioning prototype of the system should be validated in a relevant environment, in particular by using natural sunlight. Stable STH efficiencies should be demonstrated for a cumulated period of over 500 hours.

Proposals are encouraged to explore synergies with the existing or upcoming projects of the