$PH_2OTOGEN$

ACCELERATION OF PHOTOCATALYTIC GREEN HYDROGEN PRODUCTION TO MARKET READINESS THROUGH VALUE-ADDED OXIDATION PRODUCTS

Project ID	101137889
PRR 2025	Pillar 1 - H_2 Production
Call Topic	HORIZON-JTI-CLEANH$_2$-2023-01-04
Project Total Costs	2 498 813.75
Clean H_2 JU Max. Contribution	2 498 813.25
Project Period	01-01-2024 - 30-06-2027
Coordinator Beneficiary	TOYOTA MOTOR EUROPE NV, BE
Beneficiaries	SOLARONIX SA, HELMHOLTZ-ZENTRUM BERLIN FUR MATERIALIEN UND ENERGIE GMBH, STICHTING NEDERLANDSE WETENSCHAPPELIJK ONDERZOEK INSTITUTEN, LGI SUSTAINABLE INNOVATION, ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE, COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES, FRIEDRICH-ALEXANDER-UNIVERSITAET ERLANGEN-NUERNBERG

https://ph2otogen.eu/

PROJECT AND GENERAL OBJECTIVES

$PH_2OTOGEN$ aims to generate solar hydrogen through a photocatalytic reaction. While most research on photocatalytic hydrogen generation focuses on the splitting of water to form hydrogen and oxygen, $PH_2OTOGEN$ aims to couple hydrogen generation with the oxidation of an organic molecule, such as glycerol oxidation to 1,3-dihydroxyacetone (DHA), instead of oxygen formation. Some of the advantages are:

- Avoidance of the concomitant production of hydrogen and oxygen, which can result in a formation of an explosive mixture.
- Since hydrogen (gas) and DHA (oil) are in different states, they can be separated without the need for specially engineered membranes.
- The value of DHA is around 50 times higher than glycerol as a starting material, unlocking other possible revenue stream and accelerating the market-introduction of green hydrogen.

$PH_2OTOGEN$ will develop two types of efficient light-absorbing semiconductor materials: (i) a hydrogen evolving particle, and (ii) an oxidising particle.

Through efficiency and stability testing of candidate materials on laboratory scale and advanced analysis, $PH_2OTOGEN$ will provide insights into degradation mechanisms and identify countermeasures to solve these issues. The particles will be deposited on a novel transparent, conductive, porous support to allow electronic (electrons and holes) transfer between the two particle types. The synthesis of most promising materials will be scaled up and tested outdoors in a 500 cm^2 device, with a target of 5% solar to hydrogen efficiency. The technical studies, performance data and lifecycle and technoeconomic assessment will be used to select the most promising materials for scale-up and to build a business case. The technology readiness level (TRL) is expected to increase from 2-3 to 5.

NON-QUANTITATIVE OBJECTIVES

- Development of novel semiconductors and co-catalysts for hydrogen evolution and glycerol oxidation.
- Building and outdoor testing of a scalable demonstrator capable of concomitant hydrogen evolution and glycerol oxidation.
- Lifecycle, technoeconomic and market analysis of the materials and device to establish a business case.
- Advanced material analysis to elucidate degradation mechanisms and develop countermeasures.
- Engagement with research communities (through publications, conference presentations, social media and webinars) and the general public (through social media and outreach events).

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

In the first year, $PH_2OTOGEN$ focused on benchmarking semiconductor and co-catalyst materials for hydrogen evolution (HEP) and oxidation (OP) reactions using half-cell testing.

Key outcomes:

- **HEP Progress:**

  Organic semiconductors showed promising photocurrents (onset at 0.8 V), outperforming WSe^2. MoSx co-catalysts were developed and validated to boost hydrogen evolution.

- **OP Progress:**

  $BiVO_4$ (via SILAR method) and an organic semiconductor were top candidates.

  $BiVO_4$ demonstrated excellent long-term stability and has been tested under accelerated solar stress.

  MnOx was the most effective co-catalyst for glycerol oxidation.

- **Device Development:**

  A version 1 tandem device using best-performing OP and HEP is being designed for early testing. A novel transparent porous conducting support based on FTO-coated

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quartz felt has been scaled and improved with regard to conductivity and stability. A 0D model has been developed to simulate hydrogen production efficiency and to guide device design.

- **Sustainability and Market Impact:**

  Techno-economic analysis and life time assessment inventories have been completed. Glycerol supply has been identified as limiting factor for potential integration into hydrogen and green chemical sectors.

- **Communication and Outreach:**

  LinkedIn engagement reached 289 followers and two newsletters were released; dissemination targets are on track.

FUTURE STEPS AND PLANS

- Testing of promising HEP and OP in a tandem configuration.
- Development of techniques to deposit HEP and OP onto the TPCS.
- Setting up reparation activities for reactor building and small-scale testing, coupled with modelling studies to optimise the reaction design to be realised in 2026.
- Preliminary assessment of the environment impact and reactor cost.
- Continuation of dissemination and communication activities with conference participation and publications.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SoA result achieved to date (by others)	Year for reported SoA result
Project's own objectives	Develop stable and efficient tandem system	%, cm^2	Average of >5% solar-to-hydrogen (750 mmol m-2 h-1) over 500 hours with oxidation reaction forming a value-added product (> 70% purity) Size: 5 - 10 cm^2	-		H_2 production rate: 20.35 mmol·m−2·h−1	2025
	Lifecycle assessment (LCA) and technoeconomic analysis (TEA) studies to establish competitive advantage	-	LCA and TEA ready for use by partners.	Materials and process inventory prepared for TEA and LCA		TEA done for photoelectrochemical system - demonstrated to be highly competitive, LCA study done of H_2 production coupled with hydrogenation reaction	2024
	Develop stable and efficient oxidising particle (OP)	%	Activity for oxidation (tentative target: >4 mA cm-2 at 0.6 V) that matches 5% solar-to-hydrogen under sacrificial conditions over 500 hours	Photocurrent of 2.5 mA cm-2 at 0.6 V		Photocurrent of 2 mA cm-2 at 0.6 V	2024
	Demonstration device with power density 25 kWh / m2	kWh / m^2, cm^2, %	Cumulative H_2 production: 25 kWh / m2 (over 500 hours) Performance: Average of >5% solar-to-hydrogen over 500 hours with oxidation reaction forming a value-added product (>70% purity) Size: 500 cm^2	-		0.4% STH, 1 m2 (for overall water splitting)	2018
	Develop stable and efficient hydrogen evolving particle (HEP)	%	Activity equivalent to >5% solar to hydrogen efficiency (tentative target > 4 mA cm-2 at 0.6 V) under sacrificial conditions over 500 hours	2.1 mA cm-2		<0.3 mA cm-2 at 0.6 V	2022
	Modelling to define flow rates with quantitative agreement with results	-	Qualitative agreement of the model with experimental results	0D model complete which indicates sensitivity to different parameters including ionic conductivity		N/A	N/A

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