PH2OTOGEN

D8.6 – KPI Monitoring (Mid-Term)

WP8 – Task 8.4

Version 1

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Summary

This deliverable summarises the progress of the PH2OTOGEN project towards its high level and specific objectives at month 18 (out of 42) of the project. It summarises the technical progress towards a final project goal of building a 500 cm^2 demonstrator, operating for 500 hours under natural sunlight at 5% solar-to-hydrogen efficiency. It further summarises the progress towards our Communication and Dissemination targets.

Keywords

Objectives, KPIs, mid-term status

Abbreviations and acronyms

Acronym	Description
HEP	Hydrogen Evolving Particle
HLO	High Level Objective
KPI	Key Performance Indicator
LCA	Lifecycle Assessment
OP	Oxidising Particle
SpO	Specific Objective
STH	Solar-to-Hydrogen (efficiency)
TEA	Technoeconomic Analysis
TPCS	Transparent Porous Conductive Support
WP	Work Package

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Introduction

The primary goals of the PH2OTOGEN project are to develop novel materials and device design concepts to produce efficient and scalable photocatalytic sheets. Specifically, the first phase of the project has focussed on the benchmarking of hydrogen evolving particles (HEP) and oxidising particles (OP) in terms of performance (onset potentials and photocurrents measured in half-cell), stability and cost. In parallel, the transparent, porous, conductive support (TPCS), which will electrically connect the HEP and OP in the full tandem configuration (figure 1), has been improved, in terms of mechanical stability, conductivity and transparency. Furthermore, the first reactor designs are being developed through experimental and modelling studies. The final goal of the project is to build a 500 cm^2 demonstrator, operating for 500 hours under natural sunlight at 5% solar-to-hydrogen (STH) efficiency. These technical studies have been complemented by market, technoeconomic analysis (TEA) and lifecycle assessment (LCA), which have focussed on establishing PH2OTOGEN's contribution to the green hydrogen market and inventory preparation for TEA and LCA. In this report, the status of the project in achieving our objectives at month 18 (out of 42) is summarised. The reach of these and our future results are maximised through a Dissemination, Communication and Exploitation plan, whose month 18 status is also described.

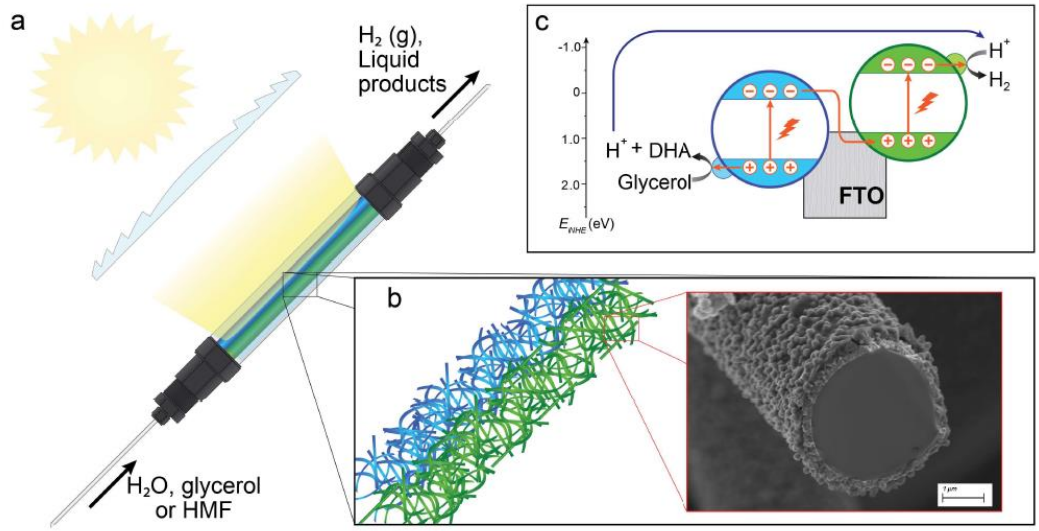

Figure 1: PH2OTOGEN concept with HEP and OP connected by the TPCS

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2 Technical KPIs

Technical KPIs were defined in the project based on the consortium's expertise and requirements in the call text: HORIZON-JTI-CLEANH2-2023-01-04. The defined KPIs could be separated into three high level objectives (HLOs):

1. Develop semiconducting particles based on abundant elements that can achieve > 5% STH
2. Build a scalable photocatalytic flow reactor (with a demonstrator of 500 cm^2 active area)
3. Establish an optimal system towards commercial viability

These were further broken down into specific objectives (SpOs). The progress of each of these HLOs and SpOs is described below.

2.1 HLO 1: Develop semiconducting particles based on abundant elements that can achieve > 5% STH

SpO	Activities to achieve the objective	KPI / Success criteria	Mid-Term Status
SpO1: Develop stable and efficient hydrogen evolving particle (HEP)	Semiconductor particles will be synthesised, tested for HER and characterised. Passivation layers, hole transport layers and co-catalysts will be added as required.	Performance: Average of > 5% solar to hydrogen efficiency under sacrificial conditions over 500 hours	One organic semiconductor material selected, which offers 4.2 mA/cm2 photocurrent (compatible with 5% STH), stable over >0.5 hour in aqueous buffer thanks to a capping transport layer. Tested in photocatalysis with molybdenum sulfide nanocatalyst: H2 is photogenerated under sacrificial conditions with glycerol at pH2. **Now performing H2 quantification, optimization of catalyst-semiconductor contact, and long-term stability tests.**
SpO2: Develop stable and efficient oxidising particle (OP)	Semiconductor particles will be synthesised, tested for oxidation reactions and characterised. Passivation layers, electron transport layers and co-catalysts will be added as required.	Performance: Activity for oxidation that matches 5% solar-to-hydrogen under sacrificial conditions over 500 hours	Two candidate absorber materials selected: $BiVO_4$ and bulk heterojunction (BHJ). $BiVO_4$ shows photocurrent >4.1 mA/cm^2 for 24 h (compatible with 5% STH) and >40% selectivity for DHA but still requires bias potential. BHJ shows sacrificial photocurrent > 20 mA/cm^2 but requires co-catalyst. **Now developing suitable co-catalyst for BHJ and optimization and long-term performance tests for $BiVO_4$.**

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SpO3: Develop stable and efficient tandem system	A photocatalyst sheet support will be developed with optimized porosity and transparency. HEP and OP synthesis will be scaled up and the resulting particles will be deposited on the photocatalyst sheet support	Performance: Average of > 5% solar-to-hydrogen over 500 hours with oxidation reaction forming a value added product (> 70% purity) Size: 5 - 10 cm^2	One organic (HEP from FAU Germany) semiconductor and W-BiVO4 (OP from DIFFER) semiconductor were employed as a tandem system for the GOR in full cell operation at 0V vs RHE. Two configurations were checked: A) Parallel and B) In series. The current density was not very phenomenal and found in the range of μA. The matching of organic and W-BiVO4 found to be not perfect as the performance dropped very fast. **Now intensifying the exchange of samples among WPs1,2,3. Going to start monthly WP3 meetings. Emphasizing the discussion during the monthly meetings between the WP1 and WP2 for the onset working potential for the tandem system (WP3).**

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2.2 HLO 2: Build a scalable photocatalytic flow reactor (with a demonstrator of 500 cm^2 active area)

SpO	Activities to achieve the objective	KPI / Success criteria	Mid-Term Status
SpO4: Modelling to define flow rates with quantitative agreement with results	Multiphysics model of the system will be prepared. It will be used to predict the effects of flow, temperature and reactant concentration on functioning of reactor.	Qualitative agreement of the model with experimental results	Prepared a model of fibrous substrate for photocatalysts. Light transfer simulations through the nanoparticle coated fibrous substrate were performed. **Multiphysics modelling is ongoing based on the design of a small-scale prototype of photocatalytic reactor.**
SpO5: Demonstration device with power density 25 kWh / m^2	Based on the model and consortium experience on photoreactors, a reactor will be designed, constructed and tested.	Power density: 25 kWh / m^2 Performance: Average of > 5% solar-to-hydrogen over 500 hours with oxidation reaction forming a value added product (> 70% purity) Size: 500 cm^2	Several types of photoreactors were designed and maded for testing various supports, materials resistance, gas and liquid leaks. The P&ID diagram for the demonstrator is ready and the design of the final photoreactor is underway. **Hydrogen tightness must be improved. Photoreactor and demonstrator designs will be adapted according to the data provided by WP 1.2.3.4 and 5.1 before fabrication begins**

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2.3 HLO 3: Establish an optimal system towards commercial viability

SpO	Activities to achieve the objective	KPI / Success criteria	Mid-Term Status
SpO6: Life Cycle assessment (LCA) and technoeconomic analysis (TEA) studies to establish competitive advantage	An inventory of raw materials and processes will be made. Preliminary LCA and TEA of OP and HEP will be done and results will be used as KPIs. Full LCA and TEA of the final system will be performed.	LCA and TEA ready for use by partners.	Inventory for LCA and TEA study is prepared which includes all raw materials and processes involved in the synthesis. The synthesis process was scaled from the typical lab-scaled methods to 1 m^2 scale with various assumptions to ensure realistic use of resources. The intermediate results show a moderate difference in production cost of the HEP on TPCS and OP on TPCS of 20 – 60 USD / m^2, depending on the semiconductor, co-catalyst and charge transport materials used. **Data input into LCA / TEA software is now on-going and a full comparison of benchmarked HEP and OP will be available in December 2025, in line with the original plan.**

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2.4 Overall Objectives

Item / Objective	Target KPIs (Call text)	PH2OTOGEN KPIs	Mid-Term Status
Solar to hydrogen efficiency	5%	5%	The mid-term performance for the OEP is consistent with a solar-to-Hydrogen of 3.7% (for BiVO4) and >5% for organic semiconductors. The current performance of the HEP is consistent with the overall solar to hydrogen efficiency >5%. Coupling the OEP and HEP to realize unassisted solar-to-Hydrogen requires further optimization of both HEP and OEP.
Stability	500 hours	Average 5% STH over 500 hours	1 hour for the moment for the photocathode; 24 hours photoanode
Demonstrator size	500 cm^2	500 cm^2	Milestone for the substrate preparation on 100cm2, on the schedule of the demonstrator
TRL	5	5	3

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3 Communication, Dissemination and Exploitation KPIs

3.1 Communication /outreach towards citizen and large public

Channel tool	Official KPIs	Mid-term Status
Public website	7500 visits by the end of the project	3588 visits
Social media (LinkedIn and X)	Combined followers: 350 – At least 2 awareness-raising campaigns	435 combined followers on LinkedIn and X 1 awareness raising campaign (December 2024)
Visual materials	Use on the website, social media and events	Visual materials integrated in the website, roll-up and leaflet used at workshops/conferences

3.2 Dissemination towards scientific community and towards students

Channel tool	Official KPIs	Mid-term Status
Scientific publications	Minimum 10 including 6 co-authored by at least 2 partners	Publications (2 HZB), 1 (EPFL),1 drafted (CEA)
Conferences/events/trade fairs participated actively	Minimum 30 in total	6 conferences attended - ECAT2025 – 11-12 February 2025 - ModVal 2025, Germany – 10/03/2025 - E-MRS Strasbourg, France - 26/05/2025 - 4ème congrès international MOMENTOM – 02/05/205 - the 11th International Symposium on Radiative Transfer (RAD-25) – 15/06/2025 - Electrochemical National Symposium, ECNS, Utrecht,

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		Netherlands – 12/05/2025
Scientific webinars	Min 2 webinars / at least 50 attendees	Action for later.
Student activities/ Student enrolment	EPFL, CEA, FAU, TME, HZB, NWO-I, guest lectures etc.	Action for later

3.3 Dissemination towards institutional stakeholders and policy makers, including the EC

Channel tool	Official KPIs	Mid-term Status
Final multi-stakeholder event	1 final event, at least 50 attendees	Action for later.
Advisory board (AdvB)	Contact at least 1 time per year and two meetings during the project	Advisory Board contacted in 2024 to explain the overview of the project and their role. Non-disclosure agreements signed in early 2025. First meeting of the Advisory Board held in April 2025 with their feedback and recommendations summarized in D8.5.

3.4 Dissemination towards industrial partners / SME

Channel tool	Official KPIs	Mid-term Status
Industry-specific webinars	Minimum 2 webinars, Minimum 50 attendees	Action for later.

Conclusion

The project is at the 18 months mark, and KPIs are properly addressed in order to be achieved by the end of the project.

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