ADVANCEPEM

ADVANCED HIGH PRESSURE AND COST-EFFECTIVE PEM WATER ELECTROLYSIS TECHNOLOGY

Project ID	101101318
PRR 2025	Pillar 1 - H_2 Production
Call Topic	HORIZON-JTI-CLEANH$_2$-2022-01-03
Project Total Costs	1 631 066.56
Clean H_2 JU Max. Contribution	1 607 330.00
Project Period	01-02-2023 - 31-01-2027
Coordinator Beneficiary	CONSIGLIO NAZIONALE DELLE RICERCHE, IT
Beneficiaries	RHODIA OPERATIONS, SPECIALTY OPERATIONS FRANCE, HSSMI TRADING LIMITED, OORT ENERGY LTD, RWE GENERATION SE, IRD FUEL CELLS A/S, Rhodia Laboratoire du Futur, SOLVAY SPECIALTY POLYMERS ITALY SPA, RWE POWER AKTIENGESELLSCHAFT

https://advancepem.eu/

PROJECT AND GENERAL OBJECTIVES

Direct production of highly pressurised hydrogen from electrolytic water splitting can allow significant amounts of energy to be saved compared with down-stream gas compression. ADVANCEPEM aims to develop a set of breakthrough solutions at materials, stack and system levels to increase hydrogen pressure and current density, while keeping the nominal energy consumption at < 50 kWh/kg H_2. Reinforced Aquivion® polymer membranes that have enhanced conductivity, a high glass transition temperature and increased crystallinity, and are able to withstand high differential pressure, have been developed for this application. To mitigate hydrogen permeation to the anode and related safety issues, efficient recombination catalysts are integrated in both the membrane and the anode structure. The new technology has been validated by demonstrating a high-pressure electrolyser of 50 kW nominal capacity in an industrial environment. The consortium comprises an electrolyser manufacturer, a membrane and catalyst supplier, a membrane electrode assembly developer and an end-user for demonstrating the system.

NON-QUANTITATIVE OBJECTIVES

- Develop a novel polymer electrolyte membrane (PEM) electrolyser able to produce hydrogen at very high pressure thus reducing the post-compression energy consumption.
- Develop a cost-effective technology allowing to achieve large-scale application of PEM electrolysers.
- Achieve a significant reduction of capital costs by minimising use of critical raw materials, developing cheap coated bipolar plates and operating the electrolyser at a high production rate while assuring high efficiency and safe operation.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

- Development of functional components and stack with the following initial results:
  - (i) Thin (90 μm) Aquivion membranes containing radical scavengers showing conductivities of about 200 mS cm-1.
  - (ii) IR-free O_2 and H_2 evolution overpotentials 120 mV cumulative vs. thermoneutral potential at 5 A cm-2 with PGM loading 1.2 mg cm-2 with an IrRu-oxide solid solution anode and Pt/C cathode catalyst.
  - (iii) Performance of 5 A cm-2 at 1.83 V/cell, 90 °C, with a total PGM loading per MEA 1.2 mg cm-2 combining Aquivion membrane/ionomer and advanced PGM catalysts.
- Design for the validation of the PEM electrolyser.

Clean Hydrogen Partnership
Co-funded by the European Union

- Definition of the most important technical, health, safety and environmental standards, technical parameters and boundary conditions with regard to installation, commissioning and testing of the new developed technology.
- Set up of the project website and identity.
- Publication of a paper on an international open access journal.
- The Data Management plan and the Communication, Dissemination and Exploitation plan were submitted and delivered.

FUTURE STEPS AND PLANS

- Development of the life cycle analysis process.
- Development of the most promising reinforced membrane based on large-scale manufacturing potential.
- Scale-up to larger batches of the oxygen evolution reaction (OER) and hydrogen evolution reaction (HER) catalysts and recombination catalyst for membrane electrode assembly (MEA) manufacturing.
- Production of large area MEAs for the stack.
- Procurement of components.
- Kick off meeting for construction site.
- Delivery of the ADVANCEPEM demonstrator.
- Trials operation phase.
- Continuation of dissemination activities.

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
	CAPEX referred to input power	€/kW	500			900	
	CAPEX referred to capacity	€/(kg/d)	1 000			2 100	
	Hydrogen output pressure	bar	200	30		30	
	Hot idle ramp time	sec	1				2020
	Cold start ramp time	sec	10			30	
	Electricity consumption @ nominal capacity	kWh/kg	50	48.6 (at cell level)		55	
Project's own objectives	Low Electrode Overpotentials	mV vs. Etn @ 5 A cm-2	200	120		N/A	N/A
	Cell performance	V@ 5 A cm-2	1.85	1.83		2.2	
	Degradation	%/1 000 h	0.25	0.1	✓	0.19	2020
	Nominal Current Density	A/cm^2	5	5		2.2	
	Cell/Stack operating temperature	°C	90	90		90	2021
	Membrane conductivity	mS cm-1	200	> 200		200	2024

Clean Hydrogen Partnership
Co-funded by the European Union

AEMELIA

ANIONIC EXCHANGE MEMBRANE WATER ELECTROLYSIS FOR HIGHLY EFFICIENCY SUSTAINABLE, AND CLEAN HYDROGEN PRODUCTION

Project ID	101137912
PRR 2025	Pillar 1 - H_2 Production
Call Topic	HORIZON-JTI-CLEANH$_2$-2023-01-01
Project Total Costs	2 764 927.00
Clean H_2 JU Max. Contribution	2 764 926.75
Project Period	01-01-2024 - 28-02-2027
Coordinator Beneficiary	COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES, FR
Beneficiaries	SPECIALTY OPERATIONS FRANCE, MATGENIX, CLAIND SRL, SINTEF AS, Rhodia Laboratoire du Futur, FUNDACION TECNALIA RESEARCH and INNOVATION, SOLVAY SPECIALTY POLYMERS ITALY SPA, CONSIGLIO NAZIONALE DELLE RICERCHE, IMPERIAL COLLEGE OF SCIENCE TECHNOLOGY AND MEDICINE, CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS

https://aemelia.eu/

PROJECT AND GENERAL OBJECTIVES

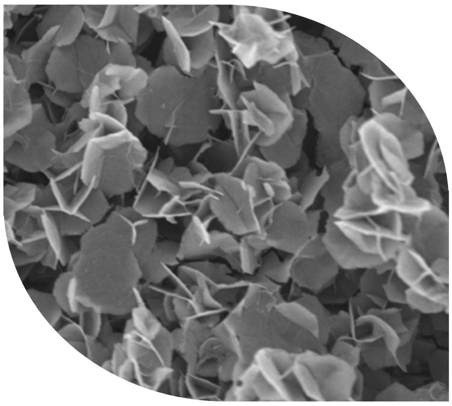
AEMELIA accepts the challenge to design and prototype an anion-exchange membrane electrolysis (AEMEL) method that meets and surpasses Hydrogen Europe's 2030 targets for performance, durability, safety and cost. For example, AEMELIA targets:

- A current-density of 1.5 A cm-2 at low voltage (1.72 V).
- An energy-efficiency of 46.2 kWh/kg or 86% of maximum theoretical efficiency, to increase H_2 production while decreasing energy consumption, compared with CLAIND's actual product ((1.76 V (47.1 kWh/kg) at 0.5 A/cm^2 in 0.2 M KOH at 42°C and 10 bar).
- A levelised cost of hydrogen of 2.5 €/kg H_2 (17% lower than the 2030 target).
- A degradation rate enabling a 10-year lifetime.
- A capital expenditure which is expected to reach 2030 targets by upscaling.

NON-QUANTITATIVE OBJECTIVES

AEMELIA intends to bring new technology for anion-exchange membrane WE based on the following:

- An innovative route for electrode preparations without ionomer.
- Implementation of recombination catalyst and electrodes without any platinum group metals in the stack.
- Increased cell efficiency through use of pulsed supply current due to small time periods for oxygen bubble release.
- Design of optimal membrane backbone and side chain to sustain high hydroxide conductive, despite high operating temperature (t> 60°C), through a machine learning approach.
- Machine learning investigation of low environmental impact solvent use to dissolve polymer for preparing ionomer dispersion solution.



PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

- Development of a data-driven methodology to support membrane optimisation using deep learning.
- Analysis of SYSENQO's Beion membrane showing high hydroxide conductivity (236 mS/cm at 50 °C), but its use is limited due to fluorination.
- Investigation of Ni_2P as the first non-PGM recombination catalyst, targeting promising activity for oxygen reduction reaction (ORR) and hydrogen evolution reaction (HER).
- Development of ionomer-free electrodes, using NiMo and NiFeB coatings with thermal treatments showing enhanced activity.
- Investigation of $NiMoS_x$ catalysts for HER, targeting overpotential reduction.
- Preliminary cell testing highlighting temperature-dependent performance differences among membranes, with Fumatech and Piperlon excelling under different conditions.
- Optimised stack design through computational fluid dynamics.
- Development of an environmental assessment method.

Clean Hydrogen Partnership
Co-funded by the European Union

FUTURE STEPS AND PLANS

Ionomer-free electrodes:

- Adhesion improvement of physical vapor deposition (PVD) based anode.
- Testing of PVD based cathode and electrodeposited anode at single cell level.
- Testing of electrode prepared with chemically activated porous transport layer (PTL) fibers at single cell level.
- Establishing cell performance and ageing tests.

Classical route of electrodes preparation avoiding fluorinated ionomer, such as Nafion:

- Testing of molybdenum sulfide-based cathode catalyst with an alternative to Nafion.
- Thermal treatment of NiFeO allowing electron conductivity enhancement of the OER catalyst.

The development on polymers should allow to down select a fluorine-free polymer able to sustain high hydroxide conductivity at 80°C. This polymer should be soluble in eco-friendly solvent. To find out this compound, the machine learning already in use needs to be fed with more data, that may come from the literature.

Beside the stack design and the importance of the position of the manifold, the flow design's influence will be investigated. A final design of the full stack will be fixed by the end of 2025, in order to start the manufacturing.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objectives	Safe and sustainable: Fluorine-free ionomers and membranes prepared with green and safe solvents via a cost-effective process.	-	No fluorine polymer and safe solvent for the ionomer dissolution.		
	Development and testing of CRM-free electrodes and PGM-free RC for AEMEL cells and stacks.	g/kW	0	0 mg/cm² on the electrodes, 0 mg/cm² for the recombination catalyst (need more additional development)	
	High performance, long lifetime, and safe components, and stack.	% @ 1.5 A/cm²	84.5	67% @ 1.2 A/cm²	
	TEA shows low-cost hydrogen towards.	€/kg	3	-	
	To ensure market entry by 2031 and ~750MW capacity by 2036 (Number of companies willing to test AEMELIA development).	Number	6	-	

CARMA-H2

CARBON-NEGATIVE PRESSURIZED HYDROGEN PRODUCTION FROM WASTE USING AN ENERGY EFFICIENT PROTONIC MEMBRANE REFORMER

Project ID	101137756
PRR 2025	Pillar 1 - H_2 Production
Call Topic	HORIZON-JTI-CLEANH$_2$-2023-01-05
Project Total Costs	12 818 293.75
Clean H_2 JU Max. Contribution	9 954 418.76
Project Period	01-10-2024 - 30-09-2028
Coordinator Beneficiary	ASOCIACION DE LA INDUSTRIA NAVARRA, ES
Beneficiaries	HAFFMANS BV, NAVARRA DE INFRAESTRUCTURAS LOCALES SOCIEDAD ANONIMA (NILSA), HERA HOLDING HABITAT, ECOLOGIA Y RESTAURACION AMBIENTAL S.L., SNAM S.P.A., SINTEF AS, FONDAZIONE ICONS, UNION ENGINEERING AS, SERVICIOS DE LA COMARCA DE PAMPLONA SA, COORSTEK MEMBRANE SCIENCES AS, SHELL GLOBAL SOLUTIONS INTERNATIONAL BV, AGENCIA ESTATAL CONSEJO SUPERIOR DE INVESTIGACIONES CIENTIFICAS

https://carma-h2.eu/

PROJECT AND GENERAL OBJECTIVES

CARMA-H2 aims to develop and demonstrate an innovative modular reactor at the Arazuri wastewater treatment plant in Navarra, Spain. The project integrates multiple technologies to transform biogas from organic waste into pressurised hydrogen (500 kg/day) and CO_2 (over 4 000 kg/day) with great energy efficiency.

At the core of CARMA-H2 is the Protonic Membrane Reformer (bioPMR), a breakthrough technology that enables direct separation of high-purity hydrogen and capture-ready CO_2 in a single, continuous step. The bioPMR will be deployed alongside three key sub-systems: a biogas pre-treatment unit, a CO_2 liquefaction system, and the existing waste-to-biogas plant at Arazuri. This fully integrated setup ensures a streamlined and highly efficient production process.

To optimise performance and scalability, CARMA-H2 will develop a digital twin, leveraging advanced computational models and control systems to enhance real-time monitoring and process efficiency.

A life cycle assessment will evaluate the CARMA-H2's environmental impact, considering waste streams, biogas sources, and energy inputs. Additionally, CARMA-H2 will assess critical raw material (CRM) usage, ensuring compliance with sustainability and regulatory standards. By combining cutting-edge hydrogen production, circular economy principles, and digital innovation, CARMA-H2 paves the way for decentralised, cost-effective hydrogen generation, supporting Europe's clean energy transition.

NON-QUANTITATIVE OBJECTIVES

CARMA-H2 is more than a technological project—it is a step toward a sustainable hydrogen ecosystem, through:

- Fostering strong collaboration with industry stakeholders and regulatory bodies in the biogas, hydrogen, and CO_2 sectors, ensuring alignment with market needs and evolving policies.
- Creating synergies with European research initiatives, particularly EURAMET's EMPIR program and the European Partnership on Metrology, to enhance hydrogen quality assurance.
- Implementing Guarantees of Origin (GOs) in Spain, to certify the renewable nature of its hydrogen and reinforcing its credibility.
- Engaging directly with end-users across mobility, industry, and energy.
- Exploring real-world hydrogen applications, ranging from urban transport and logistics to metallurgy and power generation.
- Strengthening a circular approach, minimising emissions and maximising resource efficiency by CO_2 utilisation in the agri-food and beverage sectors.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

- Start of design and construction of auxiliary facilities at the Arazuri wastewater treatment plant in Navarra, setting the stage for the installation of the innovative bioPMR.
- Analysis of renewable electricity usage to optimise energy costs and ensure a sustainable power supply for the demonstration phase.
- Ongoing efforts to enhance manufacturing capacity, with new equipment being installed at CTMS's pilot fabrication line to support the production of bioPMR components.
- Launch of CARMA-H2's communication strategy, focusing on engaging multiple audiences through the website and social media.

FUTURE STEPS AND PLANS

- Optimising each stage of the process to maximise efficiency and performance.
- Conducting a comprehensive safety assessment of all sub-systems, ensuring that every component meets the highest standards before full-scale implementation.
- Enhancing the waste-to-biogas conversion process, refining it to achieve higher efficiency and an ideal composition for seamless integration with the bioPMR unit.
- Improving the hydrogen production system by recycling gaseous streams, thereby increasing yield while simultaneously enhancing the value of the CO_2 captured through an upgraded liquefaction unit.
- Technical evaluations including testing the catalytic performance of the Protonic Membrane Reformer under real biogas conditions, alongside verifying the reliability of individual engineering units before full-scale deployment. These steps are crucial to ensuring the robustness and long-term viability of CARMA-H2's innovative technology.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?	SoA result achieved to date (by others)	Year for reported SoA result
Project's own objectives	System energy use	kWh/kg	59		64	2020
	System CAPEX	€/(kg/d)	900/2 000		1 250	2020
	System OPEX	€/kg	1.3		1.35	2020

Clean Hydrogen Partnership
Co-funded by the European Union

DJEWELS

DELFZIJL JOINT DEVELOPMENT OF GREEN WATER ELECTROLYSIS AT LARGE SCALE

Project ID	826089
PRR 2025	Pillar 1 - H_2 Production
Call Topic	FCH-02-1-2018
Project Total Costs	41 967 250.00
Clean H_2 JU Max. Contribution	10 999 999.00
Project Period	01-01-2020 - 31-12-2025
Coordinator Beneficiary	HYCC B.V., NL
Beneficiaries	MCPHY ENERGY ITALIA SOCIETA A RESPONSABILITA LIMITATA, BIOMETHANOL CHEMIE NEDERLAND B.V., MCPHY ENERGY DEUTSCHLAND GMBH, INDUSTRIE DE NORA SPA-IDN, HINICIO, MCPHY ENERGY, NOBIAN INDUSTRIAL CHEMICALS BV, NV NEDERLANDSE GASUNIE

http://www.djewels.eu

PROJECT AND GENERAL OBJECTIVES

Djewels demonstrates the operational readiness of 20 MW electrolyser for the production of green hydrogen and fuels in real-life industrial and commercial conditions. It will bring the technology from TRL 7 to TRL 8 and lay the foundation for the next scale-up step; 100 MW on the same site. Djewels will enable the development of the next generation of pressurised alkaline electrolysers, by developing more cost efficient, better performing, high current density electrodes, and is preparing the serial manufacturing of the stack and scale-up of the plant components' balance.

NON-QUANTITATIVE OBJECTIVES

Project development phase:

- Perform the engineering activities for setting up the water electrolysis system.
- Ensure safety performance: (i) completed design; (ii) completed hazard and operability analysis.
- Establish a business case for hydrogen for producing green hydrogen and develop a business plan for large scale upscaling towards 2030.

Operations:

- Evaluate technical and business model performance with regard to predictions through monitoring of system operation.
- Define the optimal operation conditions of the new high density electrode package.
- Demonstrate the reduced footprint of high-pressure alkaline electrolysis versus low pressure systems.
- Demonstrate feasibility of high-pressure alkaline electrolysis to undertake primary grid balancing services.
- Formulate and disseminate project results.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

Technical:

- Finalisation of Djewels basic engineering.
- Technology demonstration of 1 MW stack completed.
- Testing of advanced high current density electrodes on 1 MW stack completed.

Permits:

- Irrevocable environmental permit issued.
- Irrevocable water permit issued.

Financing:

- Wadden fonds subsidy for project development stage approved.
- Tailormade subsidy of 80 M Euros approved by the Dutch state.

Project management:

- Project execution and engineering plan for execution activities has been completed.

FUTURE STEPS AND PLANS

- Finalisation of project contractual agreements in entire supply chain.
- Subsequent move to project execution.
- Start of operations; Q4 2027.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	System nominal capacity	MW	20	
	Efficiency degradation @ rated power and considering 8 000 hours operations / year	% increase in energy consumption every year	1.5	
	Energy consumption	kWh/kg	< 52.8	
	CAPEX @ rated power including ancillary equipment and commissioning	M/(t/d)	5.5	
	Flexibility with a degradation <2% year	% of nominal power	3-110	
	Hot start from min to max power	%/secs	20 (ramp up) 100 (ramp down)	

Clean Hydrogen Partnership
Co-funded by the European Union

ENDURE

ALKALINE ELECTROLYSERS WITH ENHANCED DURABILITY

Project ID	101137925
PRR 2025	Pillar 1 - H_2 Production
Call Topic	HORIZON-JTI-CLEANH$_2$-2023-01-03
Project Total Costs	2 492 868.75
Clean H_2 JU Max. Contribution	2 492 868.75
Project Period	01-01-2024 - 31-12-2026
Coordinator Beneficiary	STARGATE HYDROGEN SOLUTIONS OU, EE
Beneficiaries	FUNDACION PARA EL DESARROLLO DE LAS NUEVAS TECNOLOGIAS DEL HIDROGENO EN ARAGON, PERMASCAND AB, ZENTRUM FUR SONNENENERGIE- UND WASSERSTOFF-FORSCHUNG BADEN-WURTTEMBERG, UNIVERSITE CATHOLIQUE DE LOUVAIN, FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV

https://endureh2.com/

PROJECT AND GENERAL OBJECTIVES

The main objective of the ENDURE is to bring the performance and durability of alkaline electrolysers to a new level. More specifically, to drastically decrease the degradation rate and increase the efficiency of alkaline cells and stacks through the development of hierarchically structured flow-engineered monolithic porous transport electrodes, via design/material improvements on stack level, and accelerated testing procedures. If the electrolyser degradation rate could be reduced, it would result in two-fold benefits:

- Lower operating expenditures through lower energy consumption over electrolysers' lifetime.
- Lower capital expenditures through a lower level of oversizing of the balance-of-plant components needed.

Both would positively affect the levelised cost of hydrogen (LCOH).

NON-QUANTITATIVE OBJECTIVES

ENDURE aims to make alkaline electrolysers more durable by drastically reducing the degradation rate of alkaline electrolysis cells and stacks, in order to:

- Reduce carbon emissions and mitigate climate change by enabling the widespread adoption of hydrogen as a clean and sustainable fuel source.
- Reduce the cost of hydrogen production, making it a more competitive fuel source and driving the growth of the renewable energy sector.
- Contribute to the development of a more sustainable and resilient energy system that can balance intermittent renewable energy sources with the need for a stable and continuous energy supply.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

WP1:

- An adopted report for ENDURE on harmonised test protocols provided.
- Baseline stack developed and shipped to FHa for testing.
- EIS measurement device purchased by FHa.
- Adaptations of FHa´s test rig to accommodate the baseline stack and the EIS device.

WP2:

- Via screen printing and doctor blade coated Ni foams have been characterised with X-ray tomography and tested for flow sensitivity.
- Development of a synthesis route for nickel-molybdenum coated electrodes.
- Electrochemical characterisation nickel-molybdenum electrodes showed very high HER and high OER activity.

Clean Hydrogen Partnership
Co-funded by the European Union

WP3:

- Porous material can be effectively simulated.
- Model results show good agreements with experiments.
- First three commercial diaphragm samples characterised for MacMullin number.
- Segmented PTFE gasket approach investigated.

WP4:

- Collection of degradation phenomena and stressors in cooperation with all consortium partners.

WP5:

- The consortium's Dissemination and Communication Strategy is fully defined.
- The consortium's communication tools are fully defined.
- The project website and LinkedIn page were constructed, launched and are running.
- The ENDURE exploitation plan was completed, including both joint exploitation and each partner's individual plans.

WP6:

- Kick-off meeting was held on January 9, 2024.
- Regular consortium meetings held bi-weekly.
- SharePoint folder has been set up.
- A General Assembly meeting was held on September 25, 2024.
- Risks were assessed in M9.

FUTURE STEPS AND PLANS

- Baseline stack is ready and will be delivered to FHA for testing.
- Ongoing testing in WP2 and WP4.
- Work on computer simulations in WP3; sourcing novel gasket materials and starting to build the Prototype Stack.
- General Assembly in Rotterdam.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
	Baseline degradation profile of a 10-kW electrolysis stack using pre-commercial electrodes at high current density (WP1)	Hours of operation, A/cm² current density	≥500 hours at 1 A/cm² for a prototype stack of ≥5 cells with ≥1 000 cm² electrode footprint	
	Hierarchically structured flow-engineered monolithic porous transport electrodes (PTE) with optimised bubble removal capacity (WP2)	kWh/kg, A/cm², V/cell, temperature (°C), hours	47 kWh/kg at 1 A/cm² and 80°C for 100 hours ≥1.25 A/cm² at ≤1.95V/cell	
	Developing high-performance and PGM-free catalyst coating for the HER and OER (WP2)	mV, A/cm², hours	HER < 150 mV, OER < 250 mV at ±1 A/cm² after 100 hours of electrode testing	
Project's own objectives	Upscaling of porous transport electrodes (PTE)	cm²	≥1 000 while maintaining electrochemical performance	
	Low-cost high-performance 10-kW stack prototype	€/kW, cm²	CAPEX target of 150 €/kW for a prototype stack of ≥5 cells with ≥1 000 cm² electrode footprint	
	Testing and validation of innovative stack components (WP4)	kWh/kg, A/cm², number of cells	48 kWh/kg at 1 A/cm² for a laboratory stack of ≥10 cells with ≥100 cm² electrode footprint	
	Degradation profile of a low-cost high-performance 10-kW stack	%/1 000h, hours, cm²	0.1%/1 000h over ≥500 hours for a CRM-free prototype stack of ≥5 cells with ≥1 000 cm² electrode footprint	

Clean Hydrogen Partnership
Co-funded by the European Union

EPHYRA

ESTABLISHING EUROPEAN PRODUCTION OF HYDROGEN FROM RENEWABLE ENERGY AND INTEGRATION INTO AN INDUSTRIAL ENVIRONMENT

Project ID	101112220
PRR 2025	Pillar 1 - H_2 Production
Call Topic	HORIZON-JTI-CLEANH$_2$-2022-01-08
Project Total Costs	24 705 752.39
Clean H_2 JU Max. Contribution	17 757 002.50
Project Period	01-06-2023 - 31-05-2028
Coordinator Beneficiary	MOTOR OIL (HELLAS) DIILISTIRIA KORINTHOU A.E., EL
Beneficiaries	ENVIROMETRICS TECHNIKOI SYMVOULOI ETAIREIA PERIORISMENIS EFTHYNIS, INSTITUTO TECNOLOGICO DE ARAGON, SOLUFORCE B.V., STICHTING NEW ENERGY COALITION, ENVIROMETRICS TECHNIKOI SYMVOULOI ANONYMI ETAIREIA, ENERTIME SA, SIEMENS PROCESS SYSTEMS ENGINEERING LIMITED, ETHNIKO KENTRO EREVNAS KAI TECHNOLOGIKIS ANAPTYXIS, RINA CONSULTING SPA, DEUTSCHES ZENTRUM FUR LUFT - UND RAUMFAHRT EV

https://ephyraproject.eu/

PROJECT AND GENERAL OBJECTIVES

EPHYRA will demonstrate the integration of a first-of-its-kind renewable hydrogen production facility at an industrial scale in South-eastern Europe by employing an improved electrolysis technology, at a 30 MW scale. The large-scale electrolysis will be integrated with industrial operations within Motor Oil Hellas's Corinth Refinery, one of the top refineries in Europe and the largest privately-owned industrial complex in Greece. It will be operated for at least two years under commercial conditions and will supply renewable hydrogen to the refinery's processes and external end-users.

The industrially integrated renewable hydrogen production will be developed around a circular economy, industrial symbiotic approach, as the electrolyser will be coupled with (i) renewable electricity production, (ii) an innovative waste heat harvesting technology, (iii) water use environmental optimisation, (iv) valorisation of produced oxygen in current Motor Oil Hellas's refinery operations, (v) a digital twin and (vi) a dedicated energy management system. EPHYRA will contribute to all electrolysis technology key performance indicators as detailed in the Clean Hydrogen Partnership strategic research and innovation agenda objectives. Therefore, EPHYRA will demonstrate the technology's reliability for green hydrogen production at the lowest possible cost thus enabling the EU renewable hydrogen economy, industry decarbonisation and uptake of zero-emission fuels.

NON-QUANTITATIVE OBJECTIVES

- Develop a detailed technology and integration concept for an enhanced electrolysis system.
- Optimise synergies among H_2 production, utilisation, complementary supply, and the valorisation of waste streams (waste heat, oxygen, water), within a circular economy framework.
- Develop a digital twin, controls and automation of the H_2 plant and its (symbiotic) environment.
- Set up and operate the integrated H_2 production plant and complementary supply and valorisation streams (local circular H_2 economy), including standardisation and safety aspects.
- Assess the techno-economic, environmental and societal sustainability of the H_2 production plant and the local circular H_2 economy.
- Achieve sustainable impact by stakeholder engagement, social acceptance and industrial replication (incl. business modelling and development).

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

- Major milestones such as electrolyser procurement, technical validation, and integration planning have successfully been completed.
- A tender process for the procurement of the electrolyser has been launched.
- A comprehensive evaluation of the suggested solutions was conducted, which concluded with METACON AB as the selected vendor.
- A purchase order has subsequently been placed and a solar Power Purchase Agreement (PPA) has been secured.
- A feasibility study has been conducted for integrating an Organic Rankine Cycle (ORC) system with the most cost-efficient scenario identified involving installing ORC in other refinery units rather than directly with the electrolyser by ENERTIME and MOH in providing data for evaluation.
- An economic feasibility of utilising oxygen in the refinery claus unit and a desktop study for the use of oxygen in the FCC unit were also performed. The findings of these studies are critical in guiding investment decisions and ensuring the project's alignment with the overall business strategy.
- Significant activities on digital twin design include the development of a mathematical model of the electrolyser-separator block in gPROMS, the realisation of two configurations of the electrolyser-separator block and the integrated system model, while sensitivity analysis was performed on the steady-state model to identify key performance variables affecting system performance.
- Additional models for optimisation of hydrogen production system configuration to minimise cost, the ORC for waste heat management, as well as renewable energy supply are under development.
- A comprehensive market assessment for large-scale renewable hydrogen production,

Clean Hydrogen Partnership
Co-funded by the European Union

Ephyra

especially in refineries, has been conducted where the significant replication potential in industries such as steel and chemicals was identified. The assessment also emphasised integrating green hydrogen into existing operations for decarbonisation.

- A comprehensive suite of communication and dissemination tools was developed to enhance project outreach and engagement.
- A dedicated project website was launched, serving as a central hub for project-related information and updates.
- Standardised document templates were created to ensure consistency and professionalism in project communications. A LinkedIn project account was established to facilitate networking with industry professionals and policymakers.

FUTURE STEPS AND PLANS

- Completion of the FEED study for the electrolyser, followed by detailed engineering for the integrated industrial green hydrogen production unit in order to precisely define all the technical specifications of the system as well as its operational requirements.
- Conduction of environmental study for the permitting process, as well as the necessary safety studies (HAZID, HAZOP etc) culminating in the final version of the draft safety plan.
- The GO/NO-GO decision is expected in tandem with the selection of the EPC contractor, followed by site preparation and the beginning of the construction phase, leading to the equipment's arrival.
- Conduction of basic and detailed engineering and procurement for the ORC system.
- Refinement of the models developed for the digital twin and the simulation of the auxiliary functions and the energy management system will proceed as planned.
- Further work towards techno-economic, environmental and societal sustainability of the project includes the development of a techno-economic framework and sustainability assessment and a preliminary business plan to assess the project's theoretical feasibility and long-term sustainability.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	O_2 production - Base Case	tons/year	19 322	
	Operating hours per year - Base Case	hours/year	3 945	
	O_2 production - Full Load	tons/year	39 184	
	CO_2 savings for project duration - Base Case	ktons/year	52.6	
	Availability - Full Load	%	91	
	H_2 production - Full Load	tons/year	4 898	
	H_2 production - Base Case	tons/year	2 415	
	CO_2 savings for project duration - Full Load	ktons/year	108.1	
	LCOH targeted - Full Load	€/kg H_2	2.6	
	LCOH targeted - Base Case	€/kg H_2	3.3	
	Availability - Base Case	%	45	
	Operating hours per year - Full Load	hours/year	8 000	
	Degradation	%/1 000h	≤0.11	
	Use of critical raw materials as catalysts	mg/W	< 0.6	
	Hot idle ramp time	sec	≤30	
	Cold start ramp time	sec	≤900	
	CAPEX	€/kW	≤ 480 ±10%	
	Current density	A/cm^2	> 0.6	
	O&M cost	€/(kg/d)/y	≤ 43±10%	
	Electricity consumption @ nominal capacity	kWh/kg	≤49	

Clean Hydrogen Partnership
Co-funded by the European Union

EXSOTHYC

EXSOLUTION-BASED NANOPARTICLES FOR LOWEST COST GREEN HYDROGEN VIA ELECTROLYSIS

Project ID	101137604
PRR 2025	Pillar 1 - H_2 Production
Call Topic	HORIZON-JTI-CLEANH$_2$-2023-01-01
Project Total Costs	2 495 480.00
Clean H_2 JU Max. Contribution	2 495 480.00
Project Period	01-01-2024 - 31-12-2026
Coordinator Beneficiary	STARGATE HYDROGEN SOLUTIONS OU, EE
Beneficiaries	AGFA GEVAERT NV, TECHNISCHE UNIVERSITEIT EINDHOVEN, FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV, THE UNIVERSITY COURT OF THE UNIVERSITY OF ST ANDREWS

https://exsothyc.com/

PROJECT AND GENERAL OBJECTIVES

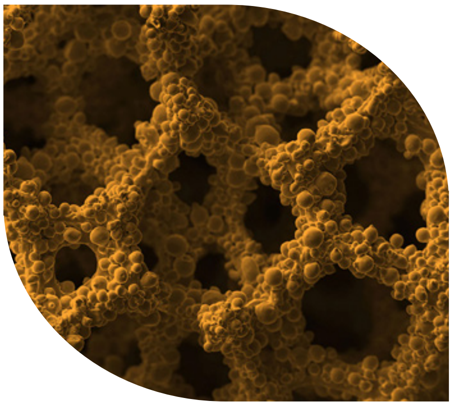
The main objective of the EXSOTHyC is to develop and validate a next generation alkaline electrolyser short-stack prototype with a novel cell design containing disruptive sub-components and breakthrough materials to fulfil the future needs of GW-sized storage of renewable energy.

NON-QUANTITATIVE OBJECTIVES

EXSOTHyC aims to contribute to scientific advances across and within different disciplines like material science, membrane science and engineering, and electrochemistry. EXSOTHyC aims to enhance EU industrial leadership for hydrogen systems and components by creating new materials, catalysts, and production methods that can be applied to other areas of renewable energy and clean technology, thus contributing to standards, the wider adoption of green hydrogen thanks to lower prices, and the growth of the renewable energy sector. EXSOTHyC aims help achieve the Green Deal goals, sustainable energy, energy security, no CO_2 emissions, cleaner air, and a lower environmental impact due to not using platinum group metals and the creation of more green jobs.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

- Obtained overpotential values of 537 mV for oxygen evolution reaction (OER) and 520 mV for hydrogen evolution reaction (HER) at a current density of 10 mA/cm^2 (1 500 rpm, 1 M KOH, 25 °C) for Co, Fe doped $LaAlO_3$ (LACFO) that was reduced at 700 °C.
- For a 0.05% Pt impregnated LACFO sample the overpotential for HER shifted into the 200 mV range. Overpotentials of 213 mV (423 mV @ 100 mA/cm^2) for OER and 163 mV (423 mV @ 100 mA/cm^2) for HER were observed at a current density of 10 mA/cm^2 in 30% KOH at 25°C.
- Novel coated diaphragms have been developed. A trade-off was observed between stability and resistance for all materials. Electrolyser testing with the novel diaphragms showed that the hydrogen-in-oxygen (HTO) can successfully be decreased compared to the reference (down to -50% at 300 mA/cm²) but at the expense of efficiency; further membrane optimisation is required.
- Catalyst coated diaphragms (CCDs) have managed to achieve 0.33 V lower cell potential at 76 °C in 30 wt.% KOH using 2.85 cm^2 large electrodes in comparison to a benchmark with Zirfon 500 and Ni felt.
- Three modified Zirfon PERL UTP 500 membranes (Zirfon B, C, D).



FUTURE STEPS AND PLANS

- Analysis of the LCTNF powder (particle size distribution, SEM/EDX, XRD).
- Optimisation of the ink composition and coating process (CCS).
- Optimisation of the sintering process and conditions (DSE).
- Further electrochemical testing.
- Resolving deposition and binding issues between perovskite oxide catalyst layer and Ni foam, to improve the performance of the structure.

Clean Hydrogen Partnership
Co-funded by the European Union

EXSOTHyC

- Further stabilisation of membranes based on polymer B and C.
- Further optimisation in terms of area specific resistance of membranes based on polymer B and C.
- In-situ electrolyser testing of optimised membranes.
- A manuscript for a scientific publication will be developed on the shunt currents.
- Development of reverse current model.
- Experimental work with reference electrode and distribution of relaxation times analysis.
- Testing of next best-performing solutions from the WPs in single-cell configuration.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Development of novel perovskite powders with exsolved nanoparticles highly active-catalyst for the hydrogen and oxygen evolution reaction.	mV	OER < 250 at 10 mA/cm², HER < 100 at 10 mA/cm²	
	Development of DSE (porous substrate coated with the novel catalyst) and CCS for AEL application exhibiting long-term stability and high electrochemical activity.	mV	HER <100 at 0.5 A/cm², OER < 250 at 0.5 A/cm²	
	Diaphragm with reduced HTO (Hydrogen-to-Oxygen) demonstrated.	%	HTO = 0.4 at 50 mA/cm²	
	Development of catalyst coated diaphragms (CCD) suitable for highly alkaline water electrolysis that lowers the cell potential compared to conventional Zirfon UTP diaphragms without increasing the hydrogen in oxygen content through gas crossover.	V	Cell potential decrease ≥ 0.3 vs. CCS	
	Development and use of a proposed accelerated stress test protocol, mimicking reverse currents during flexible operation combined with advanced cell characterisation.	% per cycle	Degradation rate < 0.0033 (cell level), < 0.0016 (electrode level)	
	Upscaling the prototype sub-components into stack level to be able to fabricate an alkaline electrolysis prototype stack.	cm²	1 000 per cell (stack active area)	
	Technology validated in a relevant environment – short stack prototype testing.	kWh/kg	< 48 at 1 A/cm² (electricity consumption)	

Clean Hydrogen Partnership
Co-funded by the European Union

HERAQCLES

NEW MANUFACTURING APPROACHES FOR HYDROGEN ELECTROLYSERS TO PROVIDE RELIABLE AEM TECHNOLOGY BASED SOLUTIONS WHILE ACHIEVING QUALITY, CIRCULARITY, LOW LCOH, HIGH EFFICIENCY AND SCALABILITY

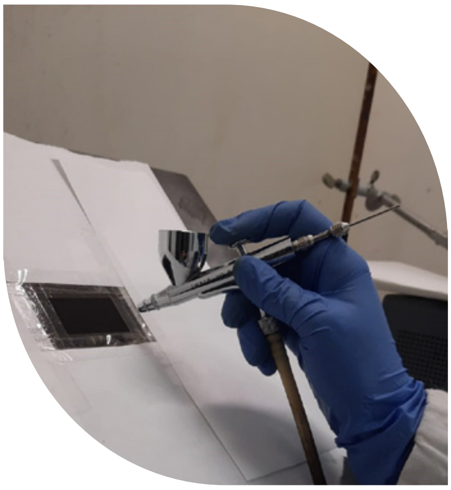
Project ID	101111784
PRR 2025	Pillar 1 - H_2 Production
Call Topic	HORIZON-JTI-CLEANH$_2$-2022-01-04
Project Total Costs	2 342 385.00
Clean H_2 JU Max. Contribution	1 999 622.50
Project Period	01-06-2023 - 31-05-2027
Coordinator Beneficiary	SCHAEFFLER TECHNOLOGIES AG and CO. KG, DE
Beneficiaries	HyGear Fuel Cell Systems B.V., JOHN COCKERILL HYDROGEN BELGIUM, EXENTIS TECHNOLOGY GMBH, HYGEAR OPERATIONS BV, HYGEAR HYDROGEN PLANT BV, HYGEAR TECHNOLOGY AND SERVICES BV, MONOLITHOS KATALITES KE ANAKIKLOSI ETAIREIA PERIORISMENIS EVTHINIS, MANUFACTURE FRANCAISE DES PNEUMATIQUES MICHELIN, HYGEAR FUEL CELL SYSTEMS BV, HYGEAR BV, VLAAMSE INSTELLING VOOR TECHNOLOGISCH ONDERZOEK N.V., CONSIGLIO NAZIONALE DELLE RICERCHE

https://www.schaeffler.com/en/technology-innovation/culture-of-innovation/funded-projects/

PROJECT AND GENERAL OBJECTIVES

HERAQCLES has the following project aims:

- Development of automated manufacturing processes for anion-exchange membrane (AEM) water electrolysers and validate a proof-of-concept 25 kW system operating at 30-50 bar with a hydrogen production rate of about 12.5 kg H_2/d (manufacturing readiness level 5) with detailed design and cost calculation for a 100 MW electrolysis plant.
- Marked increase in operating current density (1A/cm^2 nominal at 1.8 V/cell and 2 A/cm^2 at 2.2 V) while keeping energy consumption < 48 kWh/kg at 1 A/cm^2 with a stack efficiency of 80% in respect of higher heating value (~70% in respect to lower heating value). This will bring an efficiency improvement of at least 2-4 % in respect of the lower heating value compared with the present state-of-the-art in the field of liquid alkaline electrolysers while enabling operation at much higher current density.
- Reduction in capital cost in large scale production (100 MW production volume) to less than 0.6 € million/(tonnes/day H_2). This corresponds to 300 €/kW for a production volume of 100 MW. The development of an automated manufacturing process for a novel stack architecture, the use of non-critical raw materials (cheap Ni-based electrocatalysts, hydrocarbon membranes, and cost-effective Ni-coated stainless-steel bipolar plates), the minimisation of materials use, a simplified balance of plant for differential pressure operation, and the increased current density (according to the Faradays law) will bring a perspective.
- Validation of the durability under steady and intermittent duty cycles conditions in time studies of at least 2 000 hours cumulative (1 000 hours of steady-state and 1 000 hours of cycled operation) with targeted degradation rate lower than 5-7 mV/h at a fixed current density of 1 A/cm^2 corresponding to about 0.2-0.4 %/1 000 h.



- System lifetime of 10 years operation without stack replacement and of 20 years with a single stack replacement (cut-off voltage: 2.4 V).
- Significant reduction in the levelised cost of hydrogen to less than 2-3/kg H_2 with 0.6 € million/(tonnes/day H_2) in capital expenditure and operation and maintenance costs of less than € 20/(kg/day))/year assuming a € 40 /MWh renewable electricity cost and 4 000 h/year of uptime.
- Market competitiveness for green hydrogen targeting a cost of 2-3 €/kg H_2 (theoretically corresponding to about 50-75 €/MWh).

NON-QUANTITATIVE OBJECTIVES

HERAQCLES aims to address new manufacturing approaches for AEM electrolysers to provide reliable AEM technology-based solutions, directly fulfilling targets for the large-scale deployment of cheap green hydrogen. Thus, the project will contribute to the EU policy in terms of limiting the environmental impact of current hydrogen technology applications, minimising materials usage, avoiding critical raw materials, improving the cost-effectiveness of clean hydrogen solutions and reinforcing the EU's scientific and industrial ecosystem.

Clean Hydrogen Partnership
Co-funded by the European Union

FUTURE STEPS AND PLANS

- Testing of Loop 1.
- Stack defining parameters for loop 2 stack.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objectives	Voltage	V	1.8V/cell @ 1A/cm² current density	1.8V/cell at 1A/cm² achieved at single cell level by partner CNR-ITAE.	
	Hydrogen costs	€/kg	2-3		
	Electricity consumption @ nominal capacity	kWh/kg	48 kWh/kg@1A/cm²	48 kWh/kg@1A/cm² achieved for the first period at single cell level by partner CNR-ITAE.	
	CAPEX	€/(kg/d)	600	N/A	
	CAPEX	€/kW	300		
	O&M cost	€/(kg/d)/y	20		
	Degradation	%/1 000h	0.4	Prototype tested for at least 2 000 hours cumulative (steady state/dynamic) with targeted degradation rate at 5-7 µV/h at a current density of 1 A/cm² (0.2 to 0.4 %/ 1 000 h).	
	Current density	A/cm²	1	MEA performance of 1.82 V/cell at 1 A cm-2 and 50°C and 2.2 V at 3.6 A cm-2 was achieved at CNR-ITAE in the presence of a noble metal loading of 0 mg cm-2.	
	Use of critical raw materials as catalyst	mg/W		achieved for the first period at single cell level at partner CNR-ITAE.	

HOPE

HYDROGEN OFFSHORE PRODUCTION FOR EUROPE

Project ID	101111899
PRR 2025	Pillar 1 - H_2 Production
Call Topic	HORIZON-JTI-CLEANH$_2$-2022-01-10
Project Total Costs	40 287 430.00
Clean H_2 JU Max. Contribution	20 000 000.00
Project Period	01-06-2023 - 31-05-2028
Coordinator Beneficiary	LHYFE, FR
Beneficiaries	STROHM BV, DWR ECO GMBH, FRAMES ENERGY SYSTEMS BV, ERM FRANCE, CNET CENTRE FOR NEW ENERGY TECHNOLOGIES SA, PROVINCIALE ONTWIKKELINGSMAATSCHAPPIJ WEST-VLAANDEREN, ALFA LAVAL COPENHAGEN A/S, COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES

https://hope-h2.eu/

PROJECT AND GENERAL OBJECTIVES

HOPE aims to pave the way for the deployment of large-scale offshore production of renewable hydrogen. It involves developing, building and operating the first 10 MW production unit in the North Sea, off the coast of Belgium, by 2026.

The aim is to demonstrate the technical and economic viability of this offshore project, and of pipeline transport for supplying onshore customers. This unprecedentedly large-scale project (10 MW) will be able to produce up to four tonnes a day of green hydrogen at sea, which will be exported to shore through a composite pipeline, and then compressed and delivered to customers for use in industry and the transport sector. HOPE is the first offshore project of this size in the world to begin actual implementation, with the production unit and export and distribution infrastructure due to come on stream in mid-2026.

The production site will be powered by electricity supplied under power purchase agreement contracts that guarantee its renewable origin. The water used for electrolysis will be pumped from the North Sea, desalinated and purified.

The production site will comprise three units: (i) production and compression (at medium pressure) at sea; (ii) export by composite pipeline; and (iii) compression (at high pressure), storage and distribution onshore.

NON-QUANTITATIVE OBJECTIVES

HOPE will make it possible to improve the technological solutions for the production of renewable hydrogen offshore and its export onshore, helping to reduce the investment risks for much larger-scale projects in the years to come and paving the way for the production of massive quantities of renewable hydrogen in Europe.

The grant awarded by the European Commission will be used to finance the design phases, the supply of equipment and the construction work, as well as research, development and innovation work focusing mainly on optimising technological solutions and the operation of this type of infrastructure.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

HOPE's main key innovations under development are:

- Recycled offshore barge: The structure housing the production unit will be a second-hand jack-up barge, demonstrating that it is possible to transform infrastructure previously used for oil and gas and give it a second life for the production of renewable energy, while helping to reduce costs and lead times.
- 10 MW polymer electrolyte membrane electrolyser: This highly compact electrolyser will be the first of its size to be installed offshore.
- Seawater treatment system: This low-energy system which is compact, economical and able to use the heat emitted by the electrolyser, will be used for the first time to produce green hydrogen from seawater purified by evaporation.
- Underwater flexible hydrogen pipeline for hydrogen export: The hydrogen will be exported ashore via a flexible thermoplastic composite pipeline of over 1 km long, which will transport hydrogen produced at sea after being given the technical certification for this specific use.
- Completion of three permit submissions. One of them (H_2 pipeline) has been assessed and amendment is ongoing; routing review to cope with local constraints and associated QRA.
- Completion of basic engineering.
- Initiation of consultation phase.

FUTURE STEPS AND PLANS

- Completion of permit process.
- Procurement LLIFID to be submitted.
- Securing CHCI subsidy (from Belgium).

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	PEM Electrolyser electricity consumption @ nominal capacity	kWh/kg	52	54		49	2025
	Degradation	%/1 000h	0.15			0.19	2022
	Cold start ramp time	sec	10	70		30	2022

Clean Hydrogen Partnership
Co-funded by the European Union

HYIELD

A NOVEL MULTI-STAGE STEAM GASIFICATION AND SYNGAS PURIFICATION DEMONSTRATION PLANT FOR WASTE TO HYDROGEN CONVERSION

Project ID	101137792
PRR 2025	Pillar 1 - H_2 Production
Call Topic	HORIZON-JTI-CLEANH$_2$-2023-01-05
Project Total Costs	15 512 377.50
Clean H_2 JU Max. Contribution	9 999 964.63
Project Period	01-01-2024 - 31-12-2027
Coordinator Beneficiary	MAGTEL OPERACIONES SL, ES
Beneficiaries	HYDROGEN ONSITE SL, MINCATEC ENERGY SAS, AQUAMBIENTE CIRCULAR ECONOMY SOLUTIONS SL, ARISTENG SARL, CEMEX ESPANA OPERACIONES SL, WASTE TO ENERGY ADVANCED SOLUTIONS SL, SYNHELION SA, HYDROGEN ONSITE, SL, CARTAGO VENTURES SL, SINTEF AS, FUNDACIO EURECAT, ARCELORMITTAL BREMEN GMBH, LA FARGA LACAMBRA SA, CETAQUA, CENTRO TECNOLOGICO DEL AGUA, FUNDACION PRIVADA, ENAGAS SA, AGENCIA ESTATAL CONSEJO SUPERIOR DE INVESTIGACIONES CIENTIFICAS

https://hyield.eu/

PROJECT AND GENERAL OBJECTIVES

The overall objective of HYIELD is to open a new low-cost pathway for clean hydrogen production and waste management to accelerate Europe's progress towards zero-carbon and zero landfill goals. HYIELD aims to build Europe's first large-scale waste-to-hydrogen demonstration plant that will produce over 400 tonnes of green hydrogen during the project. The ambition is to develop a robust and efficient solution that will pave the way for commercial scale-up and replication across Europe, enabling the closure of landfills and production of relevant volumes of low-cost green hydrogen that can help decarbonise sectors such as shipping and heavy industry.

The demonstration plant will utilise WtEnergy Advanced Solutions' CleanTech gasification technology and H_2Site membrane separation reactor and it will be implemented at a CEMEX cement factory in Spain, where the green hydrogen will be utilised in cement production.

NON-QUANTITATIVE OBJECTIVES

- Design a multi-stage gasification, gas cleaning and gas separation process for a beyond state-of-the-art waste to hydrogen plant.
- Gain deeper knowledge of organic waste gasification reactions to identify opportunities to optimise H_2 yield.
- Develop new digital tools and models for optimising performance of waste to hydrogen plants.
- Unlock energy potential in new organic waste feedstock for the waste to hydrogen applications.
- Increase knowledge of planning and regulatory requirements for the implementation of waste-to-hydrogen plants.
- Develop and test a novel water-gas shift membrane reactor at industrial scale.
- Develop and test a novel metal hydride hydrogen storage unit at industrial scale.
- Validate the integrated waste-to-hydrogen plant at near industrial scale and in real-world setting.
- Validate clean hydrogen quality certification and clean hydrogen guarantees of origin for waste-to-hydrogen technologies.
- Benchmark the waste-to-hydrogen solution developed against other clean H_2 pathways.
- Develop a regional scale-up plan for after the project.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

The kick-off meeting, held on the 18th January 2024 in the HQ of WtEnergy Advanced Solutions located in Barcelona and was attended by all partners, along with project and financial officers from the Clean Hydrogen Partnership.

FUTURE STEPS AND PLANS

Work is commencing to define the demonstrator specification and parameters, prepare the site (including permit issuing), develop models and digital tools, and start the communication campaign, among other activities. The second general assembly is planned at the demonstration site in Spain.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?	SoA result achieved to date (by others)	Year for reported SoA result
Project's own objectives	System carbon yield	kg H_2/kg C	0.32		0.15	2020
	System CAPEX	€/(kg/d)	2 736		1 806	2020
	System OPEX	€/kg	0.328		0.013	2020
	Conversion efficiency	%	>50		40-50	2020
	Operational hours	hours	>4 000		N/A	N/A
	LCOH at target production	€/kg	< 3		1.8-3.4 (USD/kg)	2020
	Reactor size	MW	≥3		N/A	N/A
	Yearly Hydrogen Production	t/year	≥180		N/A	N/A

Clean Hydrogen Partnership
Co-funded by the European Union

HYP3D

HYDROGEN PRODUCTION IN PRESSURIZED 3D-PRINTED SOLID OXIDE ELECTROLYSIS STACKS

Project ID	101101274
PRR 2025	Pillar 1 - H_2 Production
Call Topic	HORIZON-JTI-CLEANH$_2$-2022-01-01
Project Total Costs	2 543 398.75
Clean H_2 JU Max. Contribution	2 543 398.75
Project Period	01-01-2023 - 31-12-2025
Coordinator Beneficiary	FUNDACIO INSTITUT DE RECERCA DE L'ENERGIA DE CATALUNYA, ES
Beneficiaries	VAC TRON SA, SNAM S.P.A., H2B2 ELECTROLYSIS TECHNOLOGIES SL, SAS 3DCERAM SINTO, BARCELONA SUPERCOMPUTING CENTER CENTRO NACIONAL DE SUPERCOMPUTACION, POLITECNICO DI TORINO, DANMARKS TEKNISKE UNIVERSITET

https://hyp3d.eu/

PROJECT AND GENERAL OBJECTIVES

The main goal of the HyP3D project is to deliver a new generation of ultra compact high pressure stand-alone solid oxide electrolyser cell (SOEC) stacks able to convert electricity into compressed hydrogen for power-to-gas (P2G) and hydrogen refuelling station (HRS) applications.

HyP3D manufacturing technology represents a breakthrough compared with traditional ceramics SOEC processing due to a significant reduction in the time to market (from years to months), the use of raw material (76% reduction) and the required initial investment (42% reduction from conventional cell manufacturing plants, from the first MW) while introducing great flexibility and scalability of the production lines.

NON-QUANTITATIVE OBJECTIVES

- Develop disruptive electrolyte-supported Solid Oxide Electrolysis Cells based on 3D-printed 3YSZ and 8YSZ with non-flat geometry.
- Design high-pressure sealing based on 3D-printed self-tightening joints and optimised glass sealants with enhanced adhesion by surface modification.
- Fabricate ultra-compact and lightweight kW-range stacks based on 3D-printed HyP3D cells, cost-effective flat coated interconnects and surface-modified sealants.
- Build up a neural network-based digital twin of the HyP3D stack able to run in high performance computing environments.
- Design simple SOEL systems based on standalone HyP3D stacks for the particular applications of H_2 injection in the gas grid and on-site generation for hydrogen refuelling stations.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

- The cell design design has been optimised, taking into account both printing and post-printing processes. The first generation of designed cells feature large active area corrugated membranes (45 cm^2 of projected and 72 cm^2 of real one) with embedded functionalities (gas channels) that allow the use of flat thin (200 µm) interconnects at stack level with foreseen advantages in terms of power densities.
- Large area cells 3D-printing processes (pastes formulation, printing and post-printing) were successfully optimised. 3YSZ 3D-printed cells were produced with good reproducibility, free of cracks and deformation.
- 3YSZ 3D-printed cells were successfully tested at SRU and sub-stack (three cells) level at atmospheric pressure, with performance in line with the literature considering the thickness of the electrolyte and its ionic conductivity; OCV of 0.8 V/cells in SOEC mode, injected current of 25 A corresponding to 0.55 A/cm^2 and 35 W/cell.
- One stack (18 cells) was successfully built and tested in SOEC mode at atmospheric pressure with the following recorded performances: 330 W, corresponding to: 508 W/L, 274 W/kg, 290 mA/cm^2, 3.65 kg/kW.
- Commercial glass-ceramic sealants were successfully modified in order to increase their viscosity at operating temperatures with a refractory behaviour and enhance their resistance to differential pressures and

Clean Hydrogen Partnership
Co-funded by the European Union

shear stresses generated during operations in real conditions for HyP3D stacks.

- Laser-milling of metallic interconnects and 3D printed YSZ was developed in order to increase the surface roughness of the metals in the sealing regions. Through increasing the interlocking effect and the resistance to shear stresses a roughness of 5.7 um and 4.9 um was reached respectively for Crofer22APU and YSZ. The developed joints demonstrated excellent compatibility between the interfaced materials with sound and continuous interfaces and good infiltration of the glass-ceramics inside the tracks of the milled materials.
- Interlocking sealing concept was successfully tested at room temperature and under high differential pressures. The joint laser-milled-Crofer22APU/modified glass-ceramic/laser-milled-YSZ demonstrated leakages rates below the detection limit at room temperature with 4 bar applied pressure.
- Compressive sealing concepts for high pressure were also developed by introducing 3D-structures on YSZ thanks to 3D-printing. The developed non-flat sealing geometries are suitable to be coupled with compressive mica-based sealants. The introduction of notches on YSZ improved the gas tightness with respect to the flat geometries up to 5 times at high pressures (5 bar).
  - HyP3D 3YSZ cells have been demonstrated to withstand up to 1.5 bar of unbalanced pressure across the membrane.
- Protective coatings deposition via EPD (Electrophoretic Deposition) was developed, and the sintering treatment was optimised. The resulting coatings exhibit suitable thicknesses (>10 μm) and satisfactory densification (>80%).
- Initial simplified thermo-mechanical and fluid-dynamic simulations were successfully performed on both cell and SRU models.

FUTURE STEPS AND PLANS

- Increase the level of complexity of the simulations including further elements in the assembly; current collection Ni and Ag foams. By carrying out fluid dynamic simulations of 30 cells hyP3D stack.
- Building and testing HyP3D short stack (five cells) at high pressure.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objectives	Pressure	bar	5	Ambient pressure for SRU and short stacks. HYP3D cells demonstrated to be able to resist up to 1.5 bars of unbalanced pressure across the membrane. The high pressure sealing concepts demonstrated to be able to operate at high pressures (4-5 bars).	
	Power per stack	kW	2.14	0.85 kW by (3 cells sub-stack)	
	Injected current density	A/cm²	-0.9 at 1.3V	-0.55 at 1.4V	
	Use of critical raw materials	kg/kW	0.9	2.2	
	Footprint	kW/L	3.4	0.6	
	Degradation	%/1 000h	1	5	
	Electrical consumption nominal capacity	kWh/kg	38	37.7	✓
	Cold start ramp time	hours	8	3	

Clean Hydrogen Partnership
Co-funded by the European Union

HYPRAEL

ADVANCED ALKALINE ELECTROLYSIS TECHNOLOGY FOR PRESSURISED H_2 PRODUCTION WITH POTENTIAL FOR NEAR-ZERO ENERGY LOSS

Project ID	101101452
PRR 2025	Pillar 1 - H_2 Production
Call Topic	HORIZON-JTI-CLEANH$_2$-2022-01-03
Project Total Costs	3 134 235.00
Clean H_2 JU Max. Contribution	2 653 915.00
Project Period	01-03-2023 - 28-02-2026
Coordinator Beneficiary	FUNDACION PARA EL DESARROLLO DE LAS NUEVAS TECNOLOGIAS DEL HIDROGENO EN ARAGON, ES
Beneficiaries	RHODIA OPERATIONS, SPECIALTY OPERATIONS FRANCE, VECO BV, GREEN HYDROGEN SYSTEMS A/S, Rhodia Laboratoire du Futur, AGFA GEVAERT NV, SOLVAY SPECIALTY POLYMERS ITALY SPA, FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV

http://hyprael.eu/

PROJECT AND GENERAL OBJECTIVES

HYPRAEL's goal is to develop and validate the next generation of alkaline electrolysis (AEL) for highly pressurised H_2 production (at least 80 bar). In addition, an immense increase in energy efficiency will be made possible by raising the temperature to at least 120 °C. HYPRAEL will achieve these goals and move beyond the state-of-the-art by performing research covering areas from design and advanced assessment of electrocatalysts and polymers to the engineering and process intensification of an innovative cell design in four phases: (i) materials development for pressurised electrolysis with an elevated temperature; (ii) material screening for applicability in pressurised electrolysers (both phases will be performed at lab scale and in a single cell with an area of 10 cm², 1-30 bar, 80-120 °C;(iii) scale up of the most promising materials from phase 1 and 2; and (iv) scale up of developed materials and their integration into an advanced stack.

The validation of the components scaled up in phase 3 will be performed in the existing test bench of FHa designed in the frame of the Grid integrated multi megawatt high pressure alkaline electrolysers for energy applications project (Elyntegration) at 60 bar, 120 °C,6-15 kW (pilot scale), whereas the demonstration at the target pressure of above 80 bar, at a minimum temperature of 120 °C and in a cell stack of at least 50 kW capacity will be develop by Green Hydrogen Systems in a new test bench. In addition, the HYPRAEL concept will focus on developing an energy efficient high-pressure electrolyser while addressing the circularity principle of the EU objectives for a carbon neutral economy.

NON-QUANTITATIVE OBJECTIVES

- Contributing to climate neutrality by producing green hydrogen with zero CO_2 emissions and utilising renewable energy, thereby supporting climate change mitigation.
- Advancing industry, innovation, and infrastructure by fostering technological advancements in electrolysis and promoting the development of a sustainable hydrogen infrastructure.
- Enhancing access to affordable and clean energy by providing a renewable energy source and reducing operating costs through high-pressure hydrogen production, eliminating the need for additional compression.
- Promoting responsible consumption and production by optimising resource utilisation, improving efficiency, and minimising environmental impact.
- Strengthening international cooperation by encouraging global partnerships for the development and deployment of green hydrogen technology.

Clean Hydrogen Partnership

Co-funded by the European Union

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

- Development and testing of long-term stable substrates and Raney Ni-based catalysts for hydrogen and oxygen evolution in high-temperature, pressurised electrolysis.
- Focus on achieving stability in 120°C, 40 wt.% KOH.
- Design of a new test infrastructure to accommodate these extreme conditions, as durability data for materials and sensors under such conditions is limited.
- Insight achieved into the behaviour of the Ni-based catalyst layers on Ni substrates concerning temperature, coating thickness, and substrate form factors through uniform testing.
- Adaption of the IFAM's 3EA test infrastructure in Dresden to measure at temperatures above 100°C, preventing electrolyte contamination from Si or Fe.
- Observation of a slight degradation, which can be attributed to the highly concentrated KOH solution (40 wt%). Even at 80°C, the higher concentration has a negative impact. It is worth mentioning that the catalyst system can be used as a bifunctional system for hydrogen evolution reaction and oxygen evolution reactions.
- Successful coating of AGFA separators using atmospheric plasma spraying, to improve durability under high-temperature, high-pressure electrolysis. The current separators used in state-of-the-art alkaline electrolysers are not designed for increased temperature and pressure. The optimisation strategies focused on pore structure, hydrophilicity enhancement and the thermal stability. Polymers of different families with enhanced stability have been screened for the required temperature and KOH concentration.
- Optimisation of Zirfon membrane through a method developed to reduce gas crossover caused by higher pressure.
- Upgrade of FHA's pilot-scale test bench, with component and control logic selected to meet high-pressure, high-temperature demands.

FUTURE STEPS AND PLANS

- Development of materials for pressurised electrolysis at elevated temperature.
- Screening of materials for applicability in pressurised electrolysers.
- Scale up of developed materials and integration into an advanced stack.
- Validation at relevant environment and scale.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Temperature	°C	120	
	LCOH	€/kg	≤3	
	Pressure	bar	80	
	Energy efficiency	%	improvement 2-4%LHV	
	Long-term stable and highly active materials improving stack durability for harsh environment conditions	%/1 000h	Stack degradation meeting the target of maximum 0.1 %/1 000 h efficiency loss at 1 A/cm^2.	

Clean Hydrogen Partnership
Co-funded by the European Union

HYSCALE

HYSCALE – ECONOMIC GREEN HYDROGEN PRODUCTION AT SCALE VIA A NOVEL, CRITICAL RAW MATERIAL FREE, HIGHLY EFFICIENT AND LOW-CAPEX ADVANCED ALKALINE MEMBRANE WATER ELECTROLYSIS TECHNOLOGY

Project ID	101112055
PRR 2025	Pillar 1 - H_2 Production
Call Topic	HORIZON-JTI-CLEANH$_2$-2022-01-05
Project Total Costs	5 295 799.25
Clean H_2 JU Max. Contribution	5 295 799.25
Project Period	01-06-2023 - 31-05-2027
Coordinator Beneficiary	CUTTING-EDGE NANOMATERIALS CENMAT UG HAFTUNGSBESCHRANKT, DE
Beneficiaries	HyGear Fuel Cell Systems B.V., HYGEAR OPERATIONS BV, HYGEAR HYDROGEN PLANT BV, META, HYGEAR TECHNOLOGY AND SERVICES BV, HYGEAR FUEL CELL SYSTEMS BV, HYGEAR BV, META GROUP SRL, UNIVERZA V LJUBLJANI, BEKAERT NV, DIMOSIA EPICHEIRISI ILEKTRISMOU ANONYMI ETAIREIA, CONSIGLIO NAZIONALE DELLE RICERCHE, DEUTSCHES ZENTRUM FUR LUFT - UND RAUMFAHRT EV, COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES

https://www.hyscale.eu/

PROJECT AND GENERAL OBJECTIVES

HYScale aims to upscale an advanced alkaline membrane water electrolysis technology to produce economic green hydrogen at significantly higher current densities than state-of-the-art electrolysers. The technology is free of critical raw materials, fluorinated membranes and ionomers. Unique materials and design allow for cost-effective upscaling.

HYScale focuses on optimising material synthesis – especially membranes, ionomers, electrodes and transport layers – in line with Europe's circular economy plan. A 100 kW stack with an active surface area of 400 cm^2 will be developed, capable of high-dynamic-range operation at 2 A/cm^2 at 1.85–2 V and 60°C, producing hydrogen at 15 bar. The final goal is a functional electrolyser system with a capital expenditure target of € 400 kW, validated at technology readiness level 5 in an industrially relevant environment, accelerating technology development and promoting sustainability in Europe.

NON-QUANTITATIVE OBJECTIVES

- Cross-sector collaboration: Forge a dynamic, multidisciplinary ecosystem linking academia, SMEs, and industry to drive innovation and accelerate technology adoption.
- Bridging research and market: Seamless transition from lab-scale breakthroughs to industrial implementation by integrating cutting-edge materials and scalable design strategies.
- Sustainability and circularity: Embrace Europe's circular economy principles by developing a critical raw material–free, eco-friendly technology that promotes long-term sustainability.
- System safety and reliability: Enhance the overall robustness and durability of the electrolyser system through optimised component design, rigorous testing, and strategic safety measures.
- Stakeholder engagement and knowledge transfer: Foster effective communication and dissemination of insights to ensure regulatory alignment, market readiness, and broad societal impact.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

Key achievements include:

- Upscaled materials production: enhancement of the synthesis and reproducibility of critical components—such as the AionFLX membrane and ionomer—with improved strategies to reduce hydrogen crossover and ensure safety.
- Large-area cell development: development of a 400 cm² single cell that not only matches the performance of small-scale cells at lower current densities but also excels at higher current densities, confirming its scalability.
- Durability and efficiency: extended continuous tests have shown faradaic efficiencies exceeding 98% and robust performance over prolonged operation, validating the design's long-term reliability.
- Component optimisation: development of advanced catalyst-coated substrates and improved porous transport layers, reducing catalyst loadings and production time while enhancing mass transport and adhesion.
- System integration and scalability: progress toward a fully integrated 100 kW stack is underway, with ongoing discussions on balance-of-plant design and system-level validation that will elevate the technology to TRL 5.

FUTURE STEPS AND PLANS

- Finalise the upscaling and assembly of the 100 kW electrolyser stack, ensuring all components work harmoniously under realistic operating conditions.
- Conduct comprehensive long-term and dynamic grid-condition tests to validate durability, efficiency, and safety at high current densities.
- Further optimise manufacturing processes, scaling up membrane and catalyst production, to achieve the target CAPEX of 400 €/kW and lower operating expenses.
- Deepen the assessment of the levelised cost of hydrogen and develop robust strategies for market deployment.
- Strengthen collaboration with industrial partners and end-users, ensuring smooth knowledge transfer and regulatory alignment for a successful market launch.

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	Active surface area	cm^2	400	-		65.5	2021
	System size	kW	100	-		2.4	2021
	Stack performance	A/cm @ 2V/cell	2	-		0.47	2020
	Degradation rate	µV/h	5	5	✓	N/A	N/A
	Single cell performance	A/cm^2 @2V	2	2	✓	0.7	2024

Clean Hydrogen Partnership
Co-funded by the European Union

HYSELECT

EFFICIENT WATER SPLITTING VIA A FLEXIBLE SOLAR-POWERED HYBRID THERMOCHEMICAL-SULPHUR DIOXIDE DEPOLARIZED ELECTROLYSIS CYCLE

Project ID	101101498
PRR 2025	Pillar 1 - H_2 Production
Call Topic	HORIZON-JTI-CLEANH$_2$-2022-01-06
Project Total Costs	3 982 105.00
Clean H_2 JU Max. Contribution	3 982 104.50
Project Period	01-01-2023 - 31-12-2026
Coordinator Beneficiary	DEUTSCHES ZENTRUM FUR LUFT - UND RAUMFAHRT EV, DE
Beneficiaries	GRILLO-WERKE AG, FEN RESEARCH GMBH, HELIOHEAT GMBH, AALTO KORKEAKOULUSAATIO SR, ETHNIKO KENTRO EREVNAS KAI TECHNOLOGIKIS ANAPTYXIS, AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE

https://hyselect.eu/

PROJECT AND GENERAL OBJECTIVES

HySelect proposes a solution to boost the efficiency of solar thermal water splitting by introducing two innovative core devices for the steps of the hybrid sulphur cycle (HYS): (i) a sulphuric acid splitting decomposition/sulphur-trioxide-splitting (SAD-STS) reactor that is spatially decoupled from the solar receiver and is allothermally heated using solid particles and (ii) a sulphur-dioxide-depolarised electrolyser (SDE) that does not use platinum group metals.

The ambition of HySelect is to close the technical gaps and provide the missing links in the overall, complete HYS cycle technology concept, for a realistic overall evaluation of the technology and its scale-up. The innovations to be implemented will lead to highly efficient, long-term and cost-competitive concentrated-solar-technology-driven hydrogen production.

HySelect will:

- Demonstrate the production of hydrogen by splitting water using concentrated solar technologies (CST) with an attractive efficiency and cost, through the hybrid sulphur cycle (HyS).
- Introduce, develop and operate, under real conditions, a complete H_2 production chain focusing on the SAD-STS reactor and an SDE.
- Develop and qualify non-critical materials and catalysts, for integration into plant scale prototype units for both the acid splitting reactor and the SDE unit.
- Combine experimental work with component modelling and overall process simulation culminating in a demonstration integrating HySelect's key units of a solar particle receiver, a hot particles storage system, a splitting reactor and an electrolyser into a pilot plant.
- Establish the HySelect targeted efficiency and costs through testing in a large-scale solar tower, driven with smart operation and control strategies.
- Carry out an overall process evaluation to assess the technical and economic prospects of the HySelect technology, directly linked to the know-how and developments of the sulphuric acid and water electrolysers industries.

NON-QUANTITATIVE OBJECTIVES

- Successful pilot-scale HYS technology demonstration.
- Implementation of sulphuric acid decomposition and SDE devices under industry-compatible and industry-scalable conditions.
- New approach for transferring heat from a solar receiver to endothermic catalytic reactions.
- New catalytic ways to perform SO_3 splitting.
- New sulphur dioxide depolarised electrolysers.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

- Design of flow chart of the HySelect demonstration plant with process simulation results and the main design of all relevant technology blocks is in place.
- Selection of best-performing catalytic formulations for sulphuric acid splitting (SAS), focusing on the technology blocks.
- Design of a modular pilot scale SAS Reactor.
- Investigation of the interface of the SAS reactor with the harvesting of the solar power.
- Commissioning of the solar centrifugal particle receiver.
- Demonstration of an optimised SDE cell and short stack for 50 hours, driving the design of the pilot scale electrolyser.
- Identification and assessment of technical solutions for achieving the target heat recovery. A series of heat exchangers and columns are chosen as the best commercially available technique. A critical element here is the projected cost of all the equipment; an intensive market-search based estimation identifies the essential equipment.

FUTURE STEPS AND PLANS

- Finalisation of the key elements.
- Purchasing, assembly and integration of the technology blocks.
- Conducting experimental campaigns.

Clean Hydrogen Partnership
Co-funded by the European Union

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Development of structured SO_3 splitting catalysts with high activity and long-term stability.	%	Loss of activity <10% for at least 3 000 h on stream exposure equivalent via accelerated tests.	
	Development, construction and qualification of optimised SDE stack demonstrating stack costs reduction potential of 2-3 times vs. known analogues without use of platinum group metals.	hours	Operation of at least 100 hours.	
	Scaled-up process plant layouts and techno-economic analysis (TEA) demonstrating an optimised scenario.	€/kg	Hydrogen production cost <5 €/kg.	
	Scaled-up process plant layouts and techno-economic analysis (TEA) demonstrating an optimised scenario.	€k/(kg/day)	Reduction of CAPEX starting from 15.19 in 2024 (design year) to 7.41 k€/kg/day by 2030.	
	Demonstration of on-sun and off sun solar tower testing campaigns with particle receiver prototype.	°C	Temperature drop in hot storage tank < 100 °C for 16 hours.	
	Open access publications in scientific journals.	-	>20	
	Efficient prototype heat exchanger for gas streams SO_2, SO_3, O_2, H_2O.	-	Design and construction	
	Experimental demonstration of HyS process scheme with key units (particle receiver, storage, splitting reactor, electrolyser) integrated into a pilot plant.	%	Average daily solar-to-fuel energy conversion efficiency of > 10 % based on higher heating value (HHV) and direct normal irradiance (DNI).	
	Experimental demonstration of HyS process scheme with key units (particle receiver, storage, splitting reactor, electrolyser) integrated into a pilot plant.	kg/day/m^2 receiver area	Average hydrogen production rates higher than 2.16 kg/day/m^2 receiver area.	
	Scaled-up process plant layouts and techno-economic analysis (TEA) demonstrating an optimised scenario.	€/kg	Reduction of OPEX from 0.59 in 2024 (design year) to 0.30 €/kg by 2030.	
	Demonstration of on-sun and off sun solar tower testing campaigns with particle receiver prototype.	°C	Deliver particles of temperature 900 – 1 000.	
	Gas separation system providing clean SO_2 to the SDE.	-	Design and construction.	
	Presentations at international conferences.	-	> 20	
	Upgrade and improved design of the existing particles-heated, high-efficiency lab-scale prototype sulphuric acid splitting reactor.	hours	Test operation for at least 100 hours.	
	A particles-heated prototype reactor for sulphuric acid splitting.	-	Design and construction.	
	Development of structured SO_3 splitting catalysts with high activity and long-term stability.	%	SO_3 conversion 75 of corresponding thermodynamic value.	✓
	SDE cell and short stack (5 cells) design incorporating Au catalytic materials to eliminate or minimise SO_2 carry-over from anode to cathode.	hours	Demonstration of operation <50h.	✓

HY-SPIRE

HYDROGEN PRODUCTION BY INNOVATIVE SOLID OXIDE CELL FOR FLEXIBLE OPERATION AT INTERMEDIATE TEMPERATURE

Project ID	101137866
PRR 2025	Pillar 1 - H_2 Production
Call Topic	HORIZON-JTI-CLEANH$_2$-2023-01-02
Project Total Costs	2 999 523.00
Clean H_2 JU Max. Contribution	2 999 523.00
Project Period	01-02-2024 - 31-01-2027
Coordinator Beneficiary	INSTYTUT ENERGETYKI, PL
Beneficiaries	SOLYDERA SPA, FUNDACIO INSTITUT DE RECERCA DE L'ENERGIA DE CATALUNYA, FONDAZIONE BRUNO KESSLER, ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE, DEUTSCHES ZENTRUM FUR LUFT - UND RAUMFAHRT EV, DANMARKS TEKNISKE UNIVERSITET

https://hy-spire.eu/

PROJECT AND GENERAL OBJECTIVES

Hy-SPIRE aims to boost the potential of oxide-based electrolysers (SOEL) by lowering the operating temperature below 700°C, and increasing its flexibility in order to fit with renewable energy source generation profiles. Hy-SPIRE will develop novel cells with low degradation equal to or lower than 0.75% per 1 000 hours, operation at high current densities of 1.2 A/cm^2 and the ability to operate dynamically with fast ramping. Hy-SPIRE will aim to:

- Develop oxygen ion- and proton-conducting cells (O-SOE and P-SOE) on ceramic and metallic supports, therefore analysing a broad range of technological possibilities.
- Develop new cells and stacks beyond the state-of-the-art technology in terms of designs, performance and operation.
- Conduct techno-economic analysis, supported by life cycle assessments to evaluate the project innovations and market potential.
- Define barriers and research directions to achieve SRIA objectives, such as reduction of hydrogen production cost to 3 €/kg by 2030, reduction of CAPEX 520 €/(kg/kW) and OPEX 45 €/(kg/kW).
- Design cells and stacks technologies for large-scale production, tailored for coupling with renewable energy sources and other industry sectors.

NON-QUANTITATIVE OBJECTIVES

- Optimisation of the design and materials of cells in order to allow flexible operation with reduced startup time, rapid cycling and faster stop.
- Application of thin electrolytes which substantially reduce the content of critical raw materials (CRM) in stack repeating units (SRU) paving a way for compact stack design.
- Establishing compact design of solid oxide electrolyser stacks with reduced volume which will be able to operate dynamically and easier to thermally manage.
- Establishing stacks with reduced operating temperature and reduced footprint which will ease the integration of SOEL with renewables and industrial process.
- Demonstration of the scalability of ultra high-temperature sintering which will shorten the fabrication time (by reducing thermal treatments from several hours to minutes) and the energy cost of the fabrication of the electrochemically active components of SOELs.
- Adaptation of existing and newly developed testing protocols for electrolysers which operate at the elevated temperature (i.e., SUSTAINCELL, NewSOC, FCTESQA, SOCTESQA, and the harmonised testing protocols for EU (EU harmonised testing protocols for high-temperature steam electrolysis, 2023)).

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

- Development and adaptation of testing protocols for oxygen-ion conducting solid oxide electrolysers (O-SOE) and proton-conducting solid oxide electrolysers (P-SOE). These protocols build upon and refine existing methodologies from key initiatives such as SUSTAINCELL, NewSOC, FCTESQA, and SOCTESQA, as well as the harmonised EU testing protocols for high-temperature steam electrolysis (2023).
- Establishment of standardised evaluation procedures, enabling reliable performance assessment, durability testing, and benchmarking of O-SOE and P-SOE technologies.

FUTURE STEPS AND PLANS

The developed testing protocols for single-cell Solid Oxide Electrolysers (SOE) with oxygen-ion conducting electrolytes (O-SOE) and proton-conducting electrolytes (P-SOE).

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Degradation rate	%/1 000 h	0.75	
	Current density	A/cm²	1.2	
	Thickness of the electrolyte	um	1-2	
	Hot idle ramp time	sec	240	
	Cold start ramp time	hours	6	

Clean Hydrogen Partnership
Co-funded by the European Union

MULTIPLHY

MULTIMEGAWATT HIGH-TEMPERATURE ELECTROLYSER TO GENERATE GREEN HYDROGEN FOR PRODUCTION OF HIGH-QUALITY BIOFUELS

Project ID	875123
PRR 2025	Pillar 1 - H_2 Production
Call Topic	FCH-02-2-2019
Project Total Costs	9 751 722.51
Clean H_2 JU Max. Contribution	6 993 725.39
Project Period	01-01-2020 - 31-12-2025
Coordinator Beneficiary	COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES, FR
Beneficiaries	NESTE ENGINEERING SOLUTIONS BV, NESTE NETHERLANDS BV, ENGIE ENERGIE SERVICES, NESTE ENGINEERING SOLUTIONS OY, PAUL WURTH SA, SUNFIRE GMBH, NESTE OYJ, ENGIE

http://www.multiplhy-project.eu

PROJECT AND GENERAL OBJECTIVES

MultiPLHY will demonstrate the technological and industrial leadership of the EU in solid oxide electrolyser cell (SOEC) technology with its rated electrical connection of ~3.5 MW, electrical rated nominal power of ~2.6 MWel and a hydrogen production rate of more than 670 Nm3/h. MULTIPLHY's electrical efficiency, 85 % with regard to lower heating value, will be at least 20 % higher than efficiencies of low temperature electrolysers, enabling the reduction of operational costs and the reduction of the connected load at the refinery and hence the impact on the local power grid.

MultiPLHY aims to install and integrate the world's first high-temperature electrolyser (HTE) system on a multi-MW scale at a renewable product refinery located in Rotterdam, in the Netherlands. The project's central element is the manufacturing and demonstration of a multi-MW high-temperature electrolyser and its operation in a renewable product refinery. As a result, MultiPLHY promotes the SOEC based HTE from technological readiness level 7 to 8.

NON-QUANTITATIVE OBJECTIVES

- Scale up technology to the multi-MW level by optimising efficiencies, increasing availability, improving operations and improving stack durability.
- Reduce capital cost and operation and maintenance expenditure by developing a design-to-cost strategy and refining the cost analysis.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

- The high-temperature electrolyser (HTE) and hydrogen process unit (HPU) manufacturing, commissioning and factory acceptance test (FAT) have been successfully achieved. The site was prepared (civil works, piping, mechanical, electrical, automation, instrumentation and IT). Mechanical completion of the system installation has been achieved. Commissioning of the installed equipment has taken place. The HTE is fully operational, the HPU has been operated individually and successful coupling between the HPU and HTE has been achieved.
- The design of the HTE and HPU focused on achieving high efficiency. The H_2 output was confirmed during testing of the Gen 2.1.0 module. During FAT, a quality criterion was set for an electrical consumption below 42 kWh/kgH_2. The twelve modules passed this criterion, which is an important milestone towards the final objective of 84 % LHV efficiency. The final assessment of both the efficiency and LCOH will be performed during the demonstration period.
- A service and maintenance concept has been defined. The tests performed on the Gen 2.1.0 module and HPU already contribute to a better knowledge of their reliability. The real availability will be monitored during the operation phase. Ahead of this phase, NESTE operators have been trained to operate the unit and to intervene in case of maintenance/incident. In addition, in order to minimise the downtime, spare components have been ordered and stored close to the unit for replacement as soon as possible, if needed.
- Sunfire stacks and CEA stacks have been successfully tested first in the 2-to-5 kWDC range, then, following upscaling efforts, in the 10-to-20 kWDC range. A total of more than 42 000 hours of operation was accumulated, placing MULTIPLHY at the forefront of projects in terms of durability testing, and at the scale of large stacks. ASR degradations below 15 mOhm cm²/kh, and even as low as 11 mOhm cm²/kh for some test sequences, have been measured on the latest Sunfire generation of stack.
- The operation strategy applied to both stacks, consisting of degradation compensating by an increase of the temperature resulted in stack operation without production loss.
- Reduction of capital cost and of operation and maintenance expenditures.

Clean Hydrogen Partnership
Co-funded by the European Union

- A design-to-cost strategy has been developed and the cost analysis will be refined taking into account operational data that can only be completed when the integration with the refinery is done.
- Techno-economic evaluations have been performed, providing methodology and reference values for several scenarios. Selected use cases of the steam electrolysis technology related to the production of hydrogen in biofuels refinery have been proposed and the techno-economic specifications of the SOEC system designed for industrial application have been determined. The results obtained so far show that the bigger the plant: (i) the higher the impact of electricity prices and efficiency and CAPEX total integration cost, and (ii) the lower the impact of CAPEX Stack. Lastly, in all scenarios high full load hours and lower discount rates are beneficial. Based on the aforementioned results, recommendations for future projects can be formulated.
- Attempts have been undertaken to have MultiPLHY's hydrogen certified that has proven to be a complicated and expensive process. For that reason, the certification of the hydrogen's origin was deemed neither relevant nor feasible.
- Three options for sourcing of renewable power have been described. Guarantee of origin (GO) purchase and contractualisation was found to be the only feasible option. However, the regulatory context and the RE supply options evaluated are not favourable. Due to the fact that in the end the origin of hydrogen produced in MultiPLHY will not be certified, it is not relevant to purchase renewable electricity.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?	SoA result achieved to date (by others)	Year for reported SoA result
Project's own objectives	Demonstration duration	hours	as long as possible over year 2025	⚙	longest operation reported at system level is also by Sunfire > 15 000 h (Grinhy sequence of projects)	2023
	Downtime	%	2		98%	N/A
	H_2 production loss	% / 1 000 h	1.2	✓	1.9	2017

Clean Hydrogen Partnership
Co-funded by the European Union

NOAH$_2$

NOVEL SOE ARCHITECTURES FOR HYDROGEN PRODUCTION

Project ID	101137600
PRR 2025	Pillar 1 - H_2 Production
Call Topic	HORIZON-JTI-CLEANH$_2$-2023-01-02
Project Total Costs	2 656 024.00
Clean H_2 JU Max. Contribution	2 655 084.00
Project Period	01-01-2024 - 31-12-2026
Coordinator Beneficiary	DANMARKS TEKNISKE UNIVERSITET, DK
Beneficiaries	LIBERTY POWDER METALS, GENVIA, SINTEF AS, HAUTE ECOLE SPECIALISEE DE SUISSE OCCIDENTALE, COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES, IDRYMA TECHNOLOGIAS KAI EREVNAS

https://noah2.dtu.dk/

PROJECT AND GENERAL OBJECTIVES

The overall goal of the NOAH$_2$ project is to provide a robust, cost-competitive, flexible, and durable stack concept for hydrogen production at intermediate temperatures through innovative electrode, cell, and stack designs. NOAH$_2$ will boost the electrolysis performance of solid oxide cells and stacks significantly beyond state-of-the-art through a combination of optimised structures and highly active materials, with a focus on reducing critical raw materials (CRM) and manufacturability using well-established large-scale routes for solid oxide technology. The NOAH$_2$ stack architecture relies on a metal based monolithic concept with infiltrated electrodes.

NOAH$_2$ will outline a path towards commercialisation, provide a sustainability classification with emphasis on substituting CRMs and an assessment of commercialisation potential compared to state-of-the-art SOEL, PEM, and alkaline electrolysers, and identify potential industrial players for high-volume manufacture.

Specific technical objectives for NOAH$_2$ are to:

- Reduce the costs of SOEL stacks by 50 % compared with that of state-of-the-art through (i) use of metallic instead of ceramic supporting components, (ii) integration of support layer/interconnect functionalities into a single layer, and (iii) reduction of the stack volume with at least 20 % by developing a metal based monolithic structure.
- Increase the hydrogen production rate (current density) by 20 % compared with that of the state-of-the-art, reaching 1.2 A/cm^2, through innovative electrode materials and structuring with infiltration of materials of superior electro catalytic activity at temperatures below 700 °C.
- Demonstrate commercially viable durability with degradation rates below ~0.75%/1 000 hours at the stack level.
- Reach SOEL operation in less than six hours from cold state and less than 240 seconds from hot state to enable fast dynamic operating modes, facilitated by the compact, metal based monolithic stack architecture and highly active electrodes.

NON-QUANTITATIVE OBJECTIVES

NOAH will:

- Outline a path towards commercialisation in terms of projecting costs for large scale manufacture towards MW and GW scales, reaching the 2030 targets of capital expenditure ~ 520 €/(kg/day) and operational expenditure (OPEX) ~ 45 €/(kg/day)/year.
- Provide a sustainability classification (life cycle analysis) with an emphasis on replacing critical raw materials.
- Provide an assessment of commercialisation potential compared with those of state-of-the-art SOEL, polymer electrolyte membrane, and alkaline electrolysers.
- Identify and engage with potential industrial players for high-volume manufacturing and further up-take of the project results.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?	SoA result achieved to date (by others)	Year for reported SoA result
Project's own objectives	Cell Current Density	A/cm^2	1.2		1	N/A
	Stack durability	%/1 000 h	<0.75		0.75	N/A
	Stack production costs	%	50		2 737 €/kWel - 1 210 €/kWel	2020
	Reach time to SOEL operation	hours from cold state	6		>6	N/A

Clean Hydrogen Partnership
Co-funded by the European Union

OUTFOX

OPTIMIZED UP-SCALED TECHNOLOGY FOR NEXT-GENERATION SOLID OXIDE ELECTROLYSIS

Project ID	101101439
PRR 2025	Pillar 1 - H_2 Production
Call Topic	HORIZON-JTI-CLEANH$_2$-2022-01-09
Project Total Costs	2 925 824.50
Clean H_2 JU Max. Contribution	2 925 824.00
Project Period	01-02-2023 - 31-01-2027
Coordinator Beneficiary	NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO, NL
Beneficiaries	LINQ CONSULTING AND MANAGEMENT LTD, TEKNOLOGIAN TUTKIMUSKESKUS VTT OY, CONVION OY, ELCOGEN OY, AKTSIASELTS ELCOGEN, FONDAZIONE POLITECNICO DI MILANO, SHELL GLOBAL SOLUTIONS INTERNATIONAL BV, POLITECNICO DI MILANO

http://outfoxproject.com

PROJECT AND GENERAL OBJECTIVES

The main objective of OUTFOX is to remove scale as a limiting factor in the deployment of oxide-based electrolysers (SOEL) technologies while proving their potential to become the preferred option for green hydrogen production. By combining experimental results up to the 80 kW scale with the identification of optimal cell, stack and system designs, OUTFOX will prepare SOEL for industrial scale systems of 100 MW with a levelised cost of hydrogen as low as 2.7 €/kg H_2 and applicability to mass manufacturing lines.

NON-QUANTITATIVE OBJECTIVES

OUTFOX will lead to the realisation of ground-breaking large geometric area electrolysis cells, a novel stack and module architecture and new approaches for reproducible, high-volume manufacturing. OUTFOX aims to overcome the current economic and technological SOEL roadblocks, and push Europe into the forefront of the green hydrogen technological landscape.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

Cell development:

- Reference cells for short stack and first batch 80 kW demonstration have been manufactured successfully; over 1 000 cells have been manufactured and delivered.
- OUTFOX is developing two types of scaled-up cells: (i) industrial cells with a cell area ≥300 cm^2 by ELCOAS, (ii) next generation cells with a cell area up to 900 cm^2. Industrial scaled-up cells have been developed and manufactured and have been electrochemically tested at the beginning of 2025. Next generation cells have been developed and manufactured. A current density of 1.15 A/cm^2 has been achieved at thermonetural voltage at 750 °C. The cell has been operated at minimum 0.85 A/cm^2 for more than 2 000 hours.

Stack development:

- Three reference short stacks (with 15 cells) have been manufactured. Stack 1 and 2 have cells with 400 micron thickness, while stack 3 has cells with 300 micron thickness.
- The reference stacks have been tested electrochemically under 0.5 and 0.85 A/cm^2. Each test involved a durability test under predetermined nominal operation up to 2 000 hours.

System development and module scale-up:

- A modelling tool based on computational fluid dynamics has been developed to explore aspects of SOEC stack scaling by design, considering various constraints relating to the physics of flow distribution, thermomechanics, and current density.
- The conceptual design of a larger system module using scaled-up stack is in progress. The design of 80 kW module has been updated.

Techno-economic analysis, circularity, roadmap to pilot:

- A plant/system model has been developed successfully for techno-economic and scale-up analysis. The developed system model is able to capture the plant's modularity, from the stacks to the full-sized plant, with expected capacities up to hundreds of MWel and GWel.
- Techno-economic analysis has been initiated.

FUTURE STEPS AND PLANS

- Validation of electrochemical performance of industrially scaled-up cell as single repeating unit.
- Determining an optimal cell size for near-future large-scale SOEL.
- Optimising industrial manufacturing process for scaled-up cells.
- Delivering stacks for 80 kW (first phase testing campaign).
- Installing and validating an 80 kW system in a relevant environment.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Current density	A/cm^2	0.85	
	Levelised Cost of Hydrogen	€/kg	2.7	
	Module size	kW	400	
	Footprint	m^2/MW	< 150	
	Cell area	cm^2	300 - 900	✓

Clean Hydrogen Partnership
Co-funded by the European Union

PEACE

PRESSURIZED EFFICIENT ALKALINE ELECTROLYSER (PEACE)

Project ID	101101343
PRR 2025	Pillar 1 - H_2 Production
Call Topic	HORIZON-JTI-CLEANH$_2$-2022-01-03
Project Total Costs	2 504 965.00
Clean H_2 JU Max. Contribution	2 504 964.75
Project Period	01-06-2023 - 31-05-2026
Coordinator Beneficiary	DEUTSCHES ZENTRUM FUR LUFT - UND RAUMFAHRT EV, DE
Beneficiaries	MATERIALS MATES ITALIA SRL, HYCC B.V., BRANDENBURGISCHE TECHNISCHE UNIVERSITAT COTTBUS-SENFTENBERG, GRANT GARANT SRO, TECHNISCHE UNIVERSITEIT EINDHOVEN, DANMARKS TEKNISKE UNIVERSITET

http://www.h2peace.eu/

PROJECT AND GENERAL OBJECTIVES

PEACE aims to develop a high-pressure alkaline electrolysis (AEL) technology to substantially reduce hydrogen production costs, enhancing the competitiveness of the hydrogen economy. A new concept of hydrogen production with two-stage pressurisation will be developed and demonstrated on an AEL system of more than 50 kW capable of operating at pressures exceeding 50 bar. The integration of advanced components, innovative design, and optimised operation strategies will be explored through modelling and experimental testing, ultimately aiming to demonstrate a system with impressive efficiency characteristics.

The PEACE-produced hydrogen will be already compressed, representing a significant advantage for its subsequent use in downstream processes operating with compressed hydrogen – reducing a significant share of CAPEX and OPEX of an electrolysis system for the chemical sector. PEACE places a strong emphasis on sustainability and circularity aspects – a life cycle assessment of the PEACE technology will be conducted to quantify its environmental impacts.

NON-QUANTITATIVE OBJECTIVES

The main goal of PEACE is to reduce the levelised cost of hydrogen for green H_2 production, through:

- High-efficiency stack development by incorporating advanced and qualified components that are free of precious metals.
- Implementation of an innovative two-stage pressurisation concept to decrease the compression costs for downstream integration.
- Balance of plants and auxiliary optimisation and qualification with a focus on the high-pressure operation.
- Technology demonstration by constructing and operating a newly developed pressurised and high-efficiency stack of > 50kW.
- Effective integration of the PEACE technology with downstream chemical plants to directly use the PEACE-produced hydrogen.
- Reduction of the capital cost of the system by increasing stack efficiency, reducing compression need and optimising the plant's balance.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

- The combination of advanced cell components based on non-precious materials has shown performances of at least 1.8 V to 1.95 V @ 1 A/cm^2.
- The qualifications of non-precious components are expected to reduce the costs for the structural parts of the stack and the exclusion of fluorinated plastic from the list of materials.
- The simulation scenarios have been established for the up-stream and down-stream integration and operation optimisation considering a combination of solar and wind power supplied, and two possible downstream processes: ammonia or methanol production.
- Implementation of a solid Data Management Plan based on FAIR data policy.
- Project communication strategy towards multiple audiences underway based on PEACE website (https://www.h2peace.eu/), and PEACE LinkedIn and X profiles.
- Dissemination and Exploitation Plan and quarterly issuance of PEACE Newsletter.

FUTURE STEPS AND PLANS

- Qualification of various cell- and stack components under pressurised conditions.
- Assembling of the PEACE AEL stack demonstrator with the best-performing components.
- Demonstrator enrichment with dual-stage pressurisation concept.
- Demonstrator in operation; evaluation of function, performance and characteristics simulations
- In depth analysis of sustainability and circularity aspects.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?	SoA result achieved to date (by others)	Year for reported SoA result
Project's own objectives	Max current density	A/cm^2	1.45		0.6	2020
	Overall system efficiency	%	68-72		66.7	2020
	Nominal current density	A/cm^2	1		0.6	2020
	Minimal load	% of nominal load	14		30%	2021
	Voltage efficiency (LHV)	%	62-75		55 - 62	2021
	Minimum pressurisation level	bar	50		30	2023
	Cell voltage	V	1.65-2		1.9 - 2.3	2018 - 2019
	Use of critical materials	mg/W			0.6	2020
	Specific energy use, sys	kWh/kg	49		50-59	2020
	Minimum stack size	kW	50			
	LCOH	€/kg	3		5	2020

Clean Hydrogen Partnership
Co-funded by the European Union

PH$_2$OTOGEN

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$_2$OTOGEN 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$_2$OTOGEN 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$_2$OTOGEN 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$_2$OTOGEN 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$_2$OTOGEN 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

Clean Hydrogen Partnership
Co-funded by the European Union

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

Clean Hydrogen Partnership
Co-funded by the European Union

PILOTSOEL

ADVANCED PROCESSES ENABLING LOW COST AND HIGH PERFORMING LARGE SCALE SOLID OXIDE ELECTROLYSER PRODUCTION

Project ID	101112026
PRR 2025	Pillar 1 - H_2 Production
Call Topic	HORIZON-JTI-CLEANH$_2$-2022-01-04
Project Total Costs	2 000 000.00
Clean H_2 JU Max. Contribution	2 000 000.00
Project Period	01-06-2023 - 31-05-2026
Coordinator Beneficiary	DANMARKS TEKNISKE UNIVERSITET, DK
Beneficiaries	SIA NACO TECHNOLOGIES, ELCOGEN OY, BENEQ OY, AKTSIASELTS ELCOGEN, UNIVERZA V LJUBLJANI

https://pilotsoel.dtu.dk/

PROJECT AND GENERAL OBJECTIVES

PilotSOEL will focus on innovative upscalable and low-cost solid oxide electrolysis (SOEL) component manufacturing processes, with reduced use of critical raw materials and increased waste recycling in the cell production processes, as well as and increased degree of automation in the stack assembly to reduce manufacturing cost.

PilotSOEL will develop a novel environmentally friendly water-based tape-casting process with a reduced number of process steps for half-cell production. Innovative thin protective barrier layers deposited by atomic layer deposition and physical vapour deposition, together with microstructural cell optimisation, will reduce the cell resistance, thus improving the cell performance and durability at high current operation.

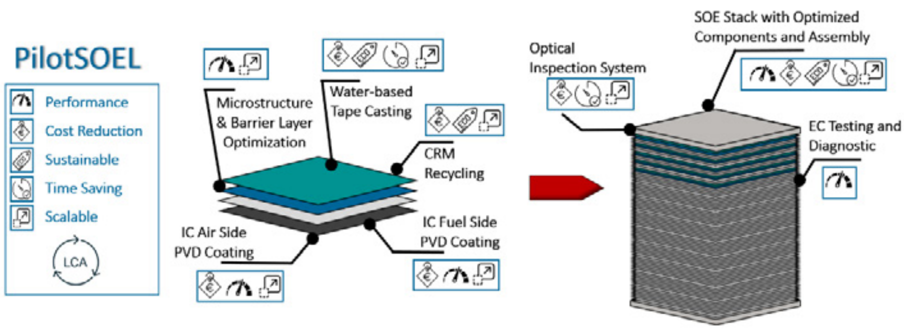
The dense and thin coating made by physical vapour deposition will improve the oxidisation resistance of the interconnector, allowing the use of cheaper alloys, and ensuring a long stack lifetime. A life-cycle assessment and a techno-economic analysis will be performed to benchmark the developed processes in PilotSOEL with the state-of-the-art SOEL production processes. PilotSOEL aims to improve the SOEL processing manufacturing readiness level (MRL) from MRL 4 to at least MRL 5 by the end of the project.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

- A review of the list of coating candidates for the air and fuel sides of interconnector plates has been undertaken.
- Design of Optical Inspection System (OIS) for stack assembly automation and quality assurance has been finalised.

FUTURE STEPS AND PLANS

PilotSOEL will continue working on optimising the manufacture routes for SOEL cell, characterising the manufactured cells and stacks, SOEL inter-connector coating and stack assembly with improved optical inspection systems.



PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Stack assembly	kW	20	
	Waste material recycle	%	Up to 100% recycle of waste tapes and comparable mechanical and electrochemical performance of the cell	
	Cells produced by water based tape casting process	Number of cells	30	
	Stack assembly defect recognition	%	> 95% accuracy in defect recognition by optical inspection system	
	Interconnector coating degradation	$mOhm.cm^2$	5 (after 3 000 hours)	✓

Clean Hydrogen Partnership
Co-funded by the European Union

PRESSHYOUS

PRESSURIZED HYDROGEN PRODUCED BY HIGH TEMPERATURE STEAM ELECTROLYSIS

Project ID	101101337
PRR 2025	Pillar 1 - H_2 Production
Call Topic	HORIZON-JTI-CLEANH$_2$-2022-01-01
Project Total Costs	2 499 426.00
Clean H_2 JU Max. Contribution	2 499 426.00
Project Period	01-09-2023 - 31-08-2026
Coordinator Beneficiary	COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES, FR
Beneficiaries	HyGear Fuel Cell Systems B.V., GENVIA, HYGEAR OPERATIONS BV, HYGEAR HYDROGEN PLANT BV, TEKNOLOGIAN TUTKIMUSKESKUS VTT OY, HYGEAR TECHNOLOGY AND SERVICES BV, AKTSIASELTS ELCOGEN, HYGEAR FUEL CELL SYSTEMS BV, HYGEAR BV, HAUTE ECOLE SPECIALISEE DE SUISSE OCCIDENTALE, ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE, NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO

PROJECT AND GENERAL OBJECTIVES

PressHyous aims to deliver relevant scientific insights on solid oxide electrolysis (SOEL) hydrogen production under pressure and to therefore foster rapid industrial empowerment, through the following goals:

- A validated lab-scale 30 bar/20 kWe stack in a pressurised vessel.
- A 10 bar pressurised stack operated without needing a pressure vessel.

NON-QUANTITATIVE OBJECTIVES

PressHyous aims to optimise individual components in large-scale HP SOEL systems using modelling tools. Currently, SOEL-stacks operate at atmospheric pressure, but pressurised operation has only been shown on a limited scale. PressHyous aims to develop a pressurised SOEL system capable of operating up to 30 bar using a pressure vessel, demonstrating its functionality at a 20 kWe scale. This will positively impact downstream equipment sizing and costs, and reduce energy consumption for compression. PressHyous will also allow for the reduction of the number of compression stages, reducing energy consumption for compression. The lack of specification for H_2 delivery conditions renders life cycle assessment results hardly comparable. A life cycle assessment of a pressurised H_2 production process based on PressHyous concepts will help identify major environmental aspects and analyse the environmental benefits of energy system integration throughout the project's use cases.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

- Definition of use cases with advisory board.
- System modelling and hazard identification to assess the feasibility of configurations in relation to the selected case studies and provide feedback for the development of stacks and system.
- Design and manufacture of two new generation cells for operation in electrolysis mode up to 30 bar.
- Operation of pressurised-stack up to 7 bars, reaching 1.5 A/cm² at the thermoneutral voltage and 750°C.
- Design of an integrated lab-scale device comprising a SOEL stack and a pressure vessel (up to 30 bar) at the scale of 20 kWe (eq. 13.5 kg H_2/day), and selection of balance of plant (e.g. vessels, stack, compression system, heat exchangers, etc.).
- Implementation of techno-economic analysis and life-cycle analysis and first analyses conducted on the selected case studies.

FUTURE STEPS AND PLANS

- Improvement of cells and other stack components for H_2 production under pressure to be continued (including interconnects, sealings, interconnect protective coatings, stack clamping system etc.).
- Finalised design, assembly, installation and validation of the long-term operation of a lab-scale device comprising a SOEL stack and a pressure vessel (up to 30 bar) at the scale of 20 kWe (eq. 13.5 kg H_2/day).
- Investigation of a promising pressurised stack concept without pressure vessel relieving the cost of plant balance.
- Lifetime of cells and stacks (without pressure vessel) to be estimated up to 30 bars.
- Supply of model-based insights for H_2 production for up to five identified use cases, on expectable performances of both stack concepts (with or without pressurised vessel) towards large scale developments, in strong link with techno-economic analysis (TEA) and life-cycle analysis (LCA).
- TEA and LCA of use cases showing the applicability and the benefits of the developed technologies and its two stack concepts versus alkaline electrolysers (AEL) and proton exchange membrane electrolysers (PEMEL) operating under pressure. This will demonstrate the viability of pressurised high temperature steam electrolysis technology for industrial use, and further increase the confidence in SOEL as a technology capable of decarbonising hard-to-abate industries.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objectives	Current density	A/cm²	-1	-1	✓
	Pressure	bar	5 - 30	7	
	Lifetime	%/kh	1	-	
	H_2 production cost	€/kg	3	-	

Clean Hydrogen Partnership
Co-funded by the European Union

PROMETEO

HYDROGEN PRODUCTION BY MEANS OF SOLAR HEAT AND POWER IN HIGH TEMPERATURE SOLID OXIDE ELECTROLYSERS

Project ID	101007194
PRR 2025	Pillar 1 - H_2 Production
Call Topic	FCH-02-2-2020
Project Total Costs	2 765 206.25
Clean H_2 JU Max. Contribution	2 499 531.25
Project Period	01-01-2021 - 30-06-2024
Coordinator Beneficiary	AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE, IT
Beneficiaries	ANGUITA FOTOVOLTAICO SL, GREEN CAPITAL POWER SL, CAPITAL ENERGY SERVICES SLU, SNAM S.P.A., STAMICARBON B.V., NEXTCHEM TECH SPA, SOLYDERA SA, Fundacion IMDEA Energia, FONDAZIONE BRUNO KESSLER, ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE

https://prometeo-project.eu

PROJECT AND GENERAL OBJECTIVES

PROMETEO aims to produce hydrogen from renewable heat and power sources using solid oxide electrolysis (SOE) in areas with low electricity prices associated with photovoltaics or wind. A 25 kWe SOE prototype (approximately 15 kg/day of H_2 production) will be developed and validated in a real production environment, combined with intermittent sources; non-programmable renewable electricity and high-temperature solar heat with thermal energy storage (TES). Partial-load operation, transients and hot stand-by periods will be studied.

NON-QUANTITATIVE OBJECTIVES

Demonstrate the capability to transfer the technology from component developers to system integrators and end-users.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

- Definition of end-user cases.
- Setting up preliminary process flow diagrams.
- Identification and laboratory-validation of TES system.
- Development of process modelling tools.

FUTURE STEPS AND PLANS

- Experimental determination of the performance map for the SOE stack and the plant balance on laboratory-scale.
- Finalisation of process flow diagrams for the 25 kWe pilot plant under different operation modes.
- Design and construction of integrated pilot plant (25 kWe).
- Shipping of pilot plant to project site.
- Analysis of case studies on multi-MW scale based on finalised process flow diagrams for the pilot plant (25 kWe).

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Demonstrate the production of hydrogen by operation of >1 000 hours: Hours of experimental validation runs of the prototype.	hours	1 000	
	Obtain Solar-to-Hydrogen energy conversion efficiency from global solar radiation to H_2 energy (LHV basis).	%	10	

Clean Hydrogen Partnership
Co-funded by the European Union

PROTOSTACK

TUBULAR PROTON CONDUCTING CERAMIC STACKS FOR PRESSURIZED HYDROGEN PRODUCTION

Project ID	101101504
PRR 2025	Pillar 1 - H_2 Production
Call Topic	HORIZON-JTI-CLEANH$_2$-2022-01-02
Project Total Costs	2 497 013.75
Clean H_2 JU Max. Contribution	2 497 013.75
Project Period	01-01-2023 - 31-12-2025
Coordinator Beneficiary	SINTEF AS, NO
Beneficiaries	DEMCON HIGH-TECH SYSTEMS EINDHOVEN B.V., DEMCON LIFE SCIENCES and HEALTHEINDHOVEN B.V., DEMCON HIGH-TECH SYSTEMS ENSCHEDE BV, ATENA SCARL - DISTRETTO ALTA TECNOLOGIA ENERGIA AMBIENTE, COORSTEK MEMBRANE SCIENCES AS, SHELL GLOBAL SOLUTIONS INTERNATIONAL BV, UNIVERSITA DEGLI STUDI DI NAPOLI PARTHENOPE, AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE, AGENCIA ESTATAL CONSEJO SUPERIOR DE INVESTIGACIONES CIENTIFICAS

https://protostack.eu/

PROJECT AND GENERAL OBJECTIVES

PROTOSTACK will create a radically new, compact and modular proton-conducting ceramic electrolyte (PCCEL) stack design with integrated hot-box for operation and delivery of hydrogen up to 30 bar. The stack will be demonstrated at 5 kW and provide a pathway for further scale-up to systems of hundreds of kW. These achievements will be an important proof of technological feasibility that will attest to the advancement of PCCEL technology from technology readiness level 2 to 4.

NON-QUANTITATIVE OBJECTIVES

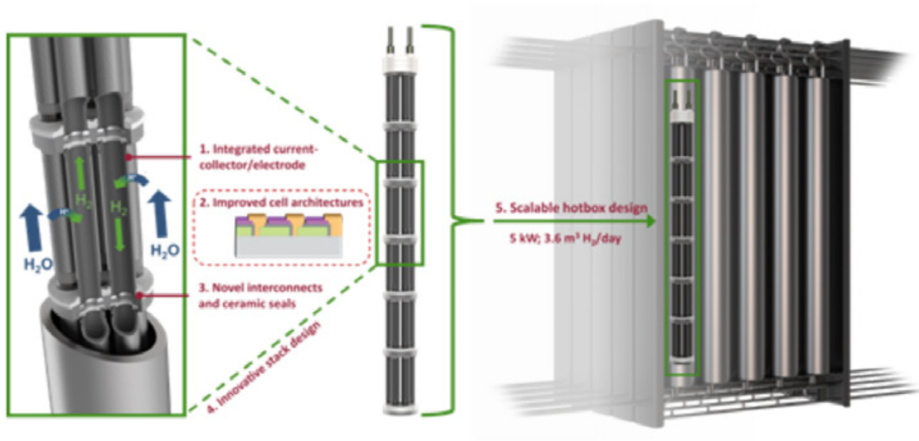
The overall consortium will engage in wide communication and dissemination activities to ensure maximum impact of the PROTOSTACK's outcomes and the industry partners have high ambition for business exploitation and commercialisation of the PROTOSTACK technology.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

- Final designs of the hot-box and stack concept have been completed.
- Production of stack components is underway.
- Validation of key cell and stack components in terms of functionality, scalable manufacturing and stability, as well as the production of the first short-stack with the new stack design for validation of the stack concept.
- Organisation of an autumn school in Valencia with more than 100 participants - mostly graduate students.

FUTURE STEPS AND PLANS

- Continued validation and optimisation of cell and stack components, and dedicated programs for stack production and testing, with emphasis on durability and performance benchmarking under varying operating conditions and delivery pressure.
- Construction and integration of the new hot-box.
- Updated system balance of plant and safety assessment.
- Detailed techno-economic and life-cycle analysis of the technology employed for specific integration scenarios and use-cases for the technology.



Stack concept and overview of key innovations in PROTOSTACK

Clean Hydrogen Partnership

Co-funded by the European Union

REACTT

RELIABLE ADVANCED DIAGNOSTICS AND CONTROL TOOLS FOR INCREASED LIFETIME OF SOLID OXIDE CELL TECHNOLOGY

Project ID	101007175
PRR 2025	Pillar 1 - H_2 Production
Call Topic	FCH-02-3-2020
Project Total Costs	2 712 322.50
Clean H_2 JU Max. Contribution	2 712 322.50
Project Period	01-01-2021 - 31-05-2025
Coordinator Beneficiary	INSTITUT JOZEF STEFAN, SI
Beneficiaries	TEKNOLOGIAN TUTKIMUSKESKUS VTT OY, BITRON SPA, SOLYDERA SA, HAUTE ECOLE SPECIALISEE DE SUISSE OCCIDENTALE, UNIVERSITA DEGLI STUDI DI SALERNO, AVL LIST GMBH, ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE, AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE, COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES

http://www.reactt-project.eu

PROJECT AND GENERAL OBJECTIVES

REACTT will realise a monitoring, diagnostic, prognostic, and control (MDPC) tool for reversible solid oxide cell (rSOC) stacks and systems to increase stack lifetime by 5 %; reach a production loss rate of 1.2 %/1 000 h; increase availability by 3 %, targeting overall availability of 98 %, and reduce operation and maintenance costs by 10 %. The additional cost of the MDPC tool will not exceed 3 % of the overall system manufacturing costs.

NON-QUANTITATIVE OBJECTIVES

- Education/training. Inclusion of the topic of solid oxide cell technologies in MSc and PhD study programmes.
- Public awareness. The web page and the dissemination material are the first step towards raising public awareness.
- Safety. Fault detection, isolation and mitigation in solid oxide electrolyser cells (SOECs) / solid oxide fuel cells (SOFCs) preclude process disruption and potential hazards.
- Regulations and standards. The formulation of a new work item proposal is to be submitted to Technical Committee 105 of the International Electrotechnical Commission.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

- Second release of the updated MDPC board with enhanced communication functionalities concerning the local system controller and the excitation unit. The platform is low-cost, yet with high computational performance, thanks to the carefully selected components and optimised hardware and software design.
- The upgraded excitation module for stack perturbation with conventional sinusoidal and non-conventional discrete random binary signal has been integrated with the MDPC board.
- An extensive experimental campaign has been conducted on two SOEC 70-cell stack boxes. Valuable and comprehensive datasets under carefully selected degradation scenarios have been acquired.
- A framework of the model-based approaches has been settled for feature extraction. It entails two types of approaches: (i) the passive approach utilising conventional signals and the simplified lumped models of the stack and system and (ii) the active approach that requires additional perturbation of the stack to get the complete fingerprint of the stack dynamics in terms of the electrochemical impedance spectra (EIS). EIS spectra are further deconvoluted and interpreted by using equivalent circuit models.
- A real-time optimisation (RTO) strategy for operating solid-oxide electrolyser (SOE) systems at optimal efficiency has been proposed. The RTO problem is formulated as a constrained nonlinear optimisation problem and, at this stage, constraint adaptation with input filtering has been selected as RTO solution approach. First simulation results were obtained on a simulated SOEC system. The proposed RTO scheme effectively pushes the system to higher levels of efficiency and maintains the system there despite perturbations by tracking active constraints.

FUTURE STEPS AND PLANS

The main activities will be focused on the final integration of the MDPC tool and its validation on the three 70-cell SOEC stacks and a 25/cell r-SOC stack.

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	Q&M cost	€/(kg/d)/y	120	The experimental campaign has not been completed so no statement can be made about where SolydEra would stand when benefiting from the technology developed.		Based on a recent inventory, no statement can be made about where competitors stand at the moment in their quality and maintenance costs.	2023
	Electrical Consumption at Rated Capacity	kWh/kg	39	34.8, achieved for the stack does not include consumption of the BoP.		40-45	2022

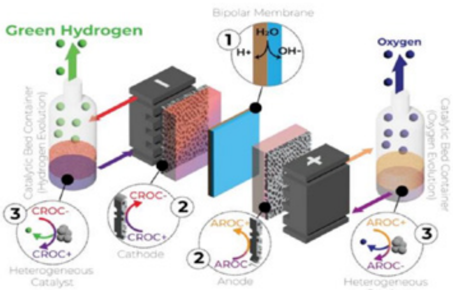
Clean Hydrogen Partnership
Co-funded by the European Union

REDHY

REDOX-MEDIATED ECONOMIC, CRITICAL RAW MATERIAL FREE, LOW CAPEX AND HIGHLY EFFICIENT GREEN HYDROGEN PRODUCTION TECHNOLOGY

Project ID	101137893
PRR 2025	Pillar 1 - H_2 Production
Call Topic	HORIZON-JTI-CLEANH$_2$-2023-01-01
Project Total Costs	2 998 988.75
Clean H_2 JU Max. Contribution	2 990 238.75
Project Period	01-01-2024 - 31-12-2027
Coordinator Beneficiary	DEUTSCHES ZENTRUM FUR LUFT - UND RAUMFAHRT EV, DE
Beneficiaries	CUTTING-EDGE NANOMATERIALS CENMAT UG HAFTUNGSBESCHRANKT, INDUSTRIE DE NORA SPA-IDN, UNIRESEARCH BV, UNIVERSITAT POLITECNICA DE VALENCIA, CONSIGLIO NAZIONALE DELLE RICERCHE, CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS

https://redhy.eu/



PROJECT AND GENERAL OBJECTIVES

REDHy aims to surpass the drawbacks of state-of-the-art electrolysers and become a pivotal technology in the hydrogen economy. The REDHy approach is highly adaptable, enduring, environmentally friendly, intrinsically secure, and cost-efficient, enabling the production of economically viable green hydrogen at considerably higher current densities than state-of-the-art electrolysers. REDHy is entirely free of critical raw materials and does not require fluorinated membranes or ionomers, while maintaining the potential to fulfil a substantial portion of the 2024 key performance indicators. A five-cell stack with an active surface area exceeding 100 cm^2 and a nominal power of 1.5 kW will be developed, capable of managing a vast dynamic range of operational capacities with economically viable and stable stack components. These endeavours will guarantee lasting and efficient performance at elevated current densities (1.5 A*cm-2 at Ecell 1.8 V/cell) at low temperatures (60 °C) and suitable hydrogen output pressures (15 bar). REDHy's ultimate objective is to create a prototype, validate it in a laboratory setting for 1 200 hours at a maximum degradation of 0.1%/1 000 hours and achieve technology readiness level 4.

NON-QUANTITATIVE OBJECTIVES

- Develop highly efficient and durable materials free of critical raw and fluorine materials for the REDHy technology to a large area short stack (five cells) with an active surface area of >100cm^2 per cell and a nominal power of >1.5 kW with adequate manufacturing quality.
- Validate the stack's efficiency and robustness when the electrical grid is fed by a large proportion of renewable energy sources or the system is directly interfaced with renewable energy sources.
- Eliminate the use of and the need for critical raw materials and fluorinated membranes and ionomers at stack level.
- Demonstrate optimisation strategies for the porous electrodes to enhance their mass transport characteristics and enhance energy efficiency.
- Demonstrate a reduced energy consumption of 48 kWh*kg-1 H_2 or less by implementing highly reversible, stable redox mediators with enhanced kinetics.
- Demonstrate a drastic reduction in interface resistances across all cell components leading to energy efficiencies > 82%.
- Demonstrate the decoupling of oxygen and hydrogen production and enabling the REDHy system to operate at a minimum 5% of partial load operation (nominal load 1.5 A/cm^2) without exceeding 0.4 % of H_2 concentration in O_2.
- Demonstrate that REDHy technology is capable of performing efficient and direct seawater electrolysis.
- Integrate the short stack in a prototype full system.
- Demonstrate the operation of the REDHy electrolyser at 1.5A*cm-2 with electricity consumption of 48 kWh*kg-1 over at least 1 200 hours of operation with a degradation of 0.1 % /1 000 hours.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

- Initiating theoretical calculations and synthesis of redox mediators.
- Initiating membranes and ionomers for bipolar membranes.
- Initiating quantification of electron transfer kinetics, modelling of the electrode, 3D printing technology and selection of electrode material.
- Initiating development of heterogeneous catalysts and first single cell tests.
- Initiating design of the 5-cell stack.
- Initiating data collection for life cycle analysis.
- Initiating the newsletter, creating and updating the website and social media and planning a workshop.

Clean Hydrogen Partnership
Co-funded by the European Union

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?	SoA result achieved to date (by others)	Year for reported SoA result
Project's own objectives	Partial load	%	5		N/A	N/A
	H_2 conc. in O_2	%	0.4			
	Short stack	Number of cells	5			
	Active area	cm²	100			
	Critical raw material free catalyst	mg/W	0		PEMWE: 2.5 / AWE: 0.6	2020
	Nominal power	kW	1.5		N/A	N/A
	Energy consumption	kWh/kg(H_2)	48		PEMWE: 55 / AWE: 50	2020
	Energy efficiencies	%	82		N/A	N/A
	Current density	A/cm²	1.5		PEMWE: 2.2 / AWE: 0.6	2020
	Hours of operation (system)	hours	1 200		N/A	N/A
	Degradation	%/1 000 h	0.1		PEMWE: 0.19 / AWE: 0.12	2020

Clean Hydrogen Partnership
Co-funded by the European Union

REFHYNE

CLEAN REFINERY HYDROGEN FOR EUROPE

Project ID	779579
PRR 2025	Pillar 1 - H_2 Production
Call Topic	FCH-02-5-2017
Project Total Costs	19 758 743.71
Clean H_2 JU Max. Contribution	9 998 043.50
Project Period	01-01-2018 - 30-06-2024
Coordinator Beneficiary	SINTEF AS, NO
Beneficiaries	ERM FRANCE, SHELL ENERGY EUROPE LIMITED, SHELL DEUTSCHLAND GMBH, ENVIRONMENTAL RESOURCES MANAGEMENT LIMITED, SPHERA SOLUTIONS GMBH, ITM POWER (TRADING) LIMITED, ELEMENT ENERGY LIMITED, STIFTELSEN SINTEF

http://www.refhyne.eu

PROJECT AND GENERAL OBJECTIVES

The overall objective of REFHYNE is to deploy and operate a 10 MW PEM electrolyser in a power-to-refinery setting. REFHYNE will validate the business model for using large-scale electrolytic hydrogen as an input to refineries, perform technical, financial and greenhouse gas analyses, and create an evidence base for the policy and regulatory changes needed to underpin the required development of this market.

NON-QUANTITATIVE OBJECTIVES

Further contributions from REFHYNE:

- REFHYNE emphasised collaboration between industry partners, bridging knowledge gaps and fostering a cross-functional team. This involved sharing learnings related to regulations, codes, standards, and technical challenges.
- REFHYNE served as a flagship initiative for decarbonising the industrial sector, demonstrating the potential of green hydrogen to reduce carbon emissions in refineries.
- Through strategic communication, workshops, and events, REFHYNE aimed to raise awareness and encourage the adoption of green hydrogen technologies across various industries.
- Establishing a pathway for future projects: REFHYNE was designed to pave the way for future large scale electrolyser projects, by providing valuable operational data, and lessons learned.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

REFHYNE is a first-of-a-kind project at the forefront of the effort to supply green refinery hydrogen for Europe. REFHYNE has installed and operated a 10MW PEM electrolyser at Shell Energy and Chemicals Park Rheinland. The final phase of REFHYNE, the successful operation of this ITM produced system, has been established including the gathering of operational data and the dissemination of emerging project results. REFHYNE has held several roundtables and workshops with stakeholders across the hydrogen value chain to demonstrate the business case and share project results.

FUTURE STEPS AND PLANS

The system is in full operation, and the electrolyser produces green hydrogen for the refinery operations. Based on the results and success of REFHYNE, Shell with partners have taken FID to realise a 100 MW PEM electrolyser from ITM Power at the same location. It is expected to be in operation from 2027.

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	Electricity consumption	kWh/kg	52	45.7 - 53.3	✓	55	2020
	Hot idle ramp time H_2 production (stacks)	sec	1	1		2	2020
	CAPEX	€/(kg/d)	2 000	-		2 100	2020
	Degradation rate	%/1 000h	0.15	<0.15		0.19	2020

Clean Hydrogen Partnership
Co-funded by the European Union

SEAL-HYDROGEN

STABLE AND EFFICIENT ALKALINE WATER ELECTROLYZERS WITH ZERO CRITICAL RAW MATERIALS FOR PURE HYDROGEN PRODUCTION

SEALHYDROGEN

Project ID	101137915
PRR 2025	Pillar 1 - H_2 Production
Call Topic	HORIZON-JTI-CLEANH_2-2023-01-01
Project Total Costs	3 000 048.75
Clean H_2 JU Max. Contribution	3 000 000.00
Project Period	01-01-2024 - 31-12-2026
Coordinator Beneficiary	UNIVERSITAT DE VALENCIA, ES
Beneficiaries	MATTECO TEAM SL, SIEMENS ENERGY GLOBAL GMBH and CO. KG, HORIBA FRANCE SAS, FORSCHUNGSZENTRUM JULICH GMBH

https://seal-hydrogen.eu/

PROJECT AND GENERAL OBJECTIVES

SEAL-HYDROGEN is an ambitious 36-month project aiming to develop laboratory-validated and scalable technology to boost the next generation of efficient, cost-effective, and durable electrolysers. SEAL-HYDROGEN proposes a multidisciplinary approach to develop an efficient and highly durable alkaline water electrolysis (AWE) stack (six cells) able to compete at the highest level with classic anion-exchange membrane (AEM) and polymer electrolyte membrane (PEM) electrolysers. A reliable method based on Raman spectroscopy, will be developed for the precise determination of electrode stability, offering appropriate quality control of great interest, both in research and industry.

NON-QUANTITATIVE OBJECTIVES

Key innovations include:

- Cost-effective layered double hydroxide (LDH) catalysts free of critical raw materials for the oxygen evolution reaction.
- Thermo-mechanical stable catalyst-support-ionomer electrodes.
- Advanced separator-electrode assemblies.
- Cutting-edge in-operando Raman spectroscopy for catalyst activity and stability testing.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

- Kick off Meeting held in Valencia, Spain, 1-2nd February 2024.
- Synthesis of various binary and ternary LDHs with different transition metals achieved. Chemical and morphological characterisation is ongoing and electrochemical tests will follow.
- Upscaling of NiFe LDH to Kg scale.
- Preparation of a large surface area electrode for testing.
- Definition of specifications for a new Raman cell to be developed.
- Study of the dissolution of NiFe LDHs through SFC coupled to ICP-MS, showing promising preliminary results on Matteco LDH stability.
- Construction of the stack test station initiated. Design finalised, holding specifications on Ni substrate properties for the constructed stack.

FUTURE STEPS AND PLANS

- Initial selection of active platinum group metal-free catalysts based on LDHs for the oxygen evolution reaction.
- Webpage, social media profiles and leaflets put in place and shared among stakeholders in various European events.
- Consortium engagement and deliverables up to date (next consortium meeting in Lille, France).
- In-operando Raman cell designed and being evaluated.
- Electrochemical tests of reference catalysts under realistic conditions for alkaline water electrolysis performed.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Interface resistance	-	1.9 V at 0.8 A/cm^2, 48 kWh/Kg	
	Electricity consumption in stacks	kWh/Kg	1.9 V at 0.8 A/cm^2, 48 kWh/Kg	
	Partial load operation	%	5	
	CRM	mg/W Pt	<0.3 mg/W	
	Stability - Current	A/cm^2	1	

Clean Hydrogen Partnership
Co-funded by the European Union

X-SEED

EXPERIMENTAL SUPERCRITICAL ELECTROLYSER DEVELOPMENT

Project ID	101137701
PRR 2025	Pillar 1 - H_2 Production
Call Topic	HORIZON-JTI-CLEANH$_2$-2023-01-01
Project Total Costs	2 989 495.00
Clean H_2 JU Max. Contribution	2 989 495.00
Project Period	01-01-2024 - 30-06-2027
Coordinator Beneficiary	ACONDICIONAMIENTO TARRASENSE ASSOCIACION, ES
Beneficiaries	SNAM S.P.A., PARTICULAR MATERIALS SRL, INDUSTRIE DE NORA SPA-IDN, DANMARKS TEKNISKE UNIVERSITET

https://www.xseedproject.eu/

PROJECT AND GENERAL OBJECTIVES

X-SEED aims to develop an innovative electrolyser that does not use an alkaline membrane and that works in supercritical water conditions (SCWC, >374 oC; >220 bar) generating high-quality H_2 at pressures over 200 bar. Novel catalysts and electrodes are designed, synthesised, and characterised to ensure high levels of efficiency. Multiscale modeling and cell design ensure laminar fluid flows, allowing H_2 and O_2 separation without a membrane. X-SEED validates results at the laboratory scale (technology readiness level 4) for a single cell and a five-cell stack achieving high energy efficiency (42 kWh/kg H_2), current density (> 3 A/cm^2), and robustness (degradation rate 1%/1 000h). X-SEED also integrates circularity and sustainability assessments in decision-making, limiting the use of critical raw materials (CRM) (use of less than 0.3 mg/W) and using waste water both for catalyst production and as a possible electrolyte for the supercritical electrolyser.

NON-QUANTITATIVE OBJECTIVES

- Maximise the efficiency, sustainability and stability of the innovative nanostructured catalysts and electrodes for anode and cathode based on earth abundant materials.
- Improve the efficiency, cost, and durability of the electrolyser by developing an innovative electrolysis cell and short stack, that do not use an electrolysis membrane, based on use in supercritical water conditions (SPWC).
- Gather evidence of the sustainability and circularity benefits of SPWC electrolyser over current solutions (proton-exchange membrane electrolysis (PEMEL), alkaline water electrolysis (AWEL)) by assessing the economic (life cycle costing), environmental (life cycle assessment) and social (social life-cycle assessment) impacts.
- Demonstrate the improvement of the sustainability and cost competitiveness of the SPWC electrolyser in comparison with PEMEL and AWEL technology.
- Contribution to scientific advances and creation of social awareness and acceptance of green H_2 economy.
- Ensuring exploitation of materials, components, and technologies developed in X-SEED project.

PROGRESS, MAIN ACHIEVEMENTS AND RESULTS

- Definition of SPWC electrolyser framework: state of art of catalyst and electrodes, survey of industrial wastewater to be used as source of catalyst and electrolyte, survey of industrial thermal waste appropriate for operation of SPWC electrolyser (no IR / no Horizons Results Platform).
- SPWC cell and stack design through 2D and multiphysics simulation.
- Synthesis of first batch of nanostructured catalyst stable at SPWC. Catalyst are based on perovskites, metal oxides and transition metal decorated nanoparticles structures.

FUTURE STEPS AND PLANS

- Selection of waste water suitable for catalyst synthesis via hydrothermal supercritical processes.
- Selection of electrolyte to use at SPWC electrolyser.
- Selection of waste thermal energy form industries suitable to operate the SPWC.
- Electrochemical and physic-chemical characterisation of catalyst and synthesis of improved catalysts.
- Electrode design and development based on high stability materials and synthesised catalysts.
- Start the design and preparation of test bench to operate and evaluate SPWC electrolysis cell.

Clean Hydrogen Partnership
Co-funded by the European Union

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?	SoA result achieved to date (by others)	Year for reported SoA result
Project's own objectives	Production capacity (Synthesis of catalysts using up-scalable processes -supercritical hydrothermal and electrospinning)	kg/h	1		tn per day is possible for different manufacturing techniques and types of catalyst (not achieved in the article but indicated as a basis for the technoeconomic analysis done in the study) CHFS process: 130 g/h	2018; 2016; 2017; 2011;
	Metals (Ni, Co, Cu, etc.) for the catalyst used coming from wastewater (e.g. mining, galvanic, etc.) using Continuous Hydrothermal Flow Synthesis process	% of metals from wastewater	50		N/A	N/A
	Catalysts with high surface area	m2/g	>10		> 100 m2/g	2020
	Catalyst and electrodes with high electrolytic efficiency. For HER and for OER	mVη10 @ NTP	< 100 for HER < 150 for OER		90 for HER 150 for OER	2021
	High stability catalyst and electrodes (in the electrochemical, thermal, and chemical aging tests).	%/1 000h	< 0.8		N/A	N/A
	Cell and stack electrolyser works at current density	A/cm^2 @ 1.8 V at SPWC	3		35 A/cm^2 3 A/cm^2 at 2.5V	2023; 2022
	Validate at laboratory scale a short stack supercritical electrolyser integrated by 5 cells of 25 cm^2	kW	0.5		for SPWC electrolyser only single cell has been tested	N/A
	Validate electricity consumption at nominal capacity	kWh/kg of H_2	42		47-66 for PEML and AWEL 35 -50 for SOEL at stack level	2020
	Produce H_2 at P	bar	> 200		30 (PEMEL, AWEL) test at 300 bar are realised for SPWC	2020; 2022; 2022
	Separation of products (O_2 and H_2) ensuring that outflows are outside the flammability limits of mixtures at operating temperatures and pressures	% of H_2 @ O_2 gas stream	< 4		N/A	N/A
	Degradation rate, demonstrated by aging stress tests at SPWC cell and stack level	%/1 000h	< 1		N/A	N/A
	High operational flexibility: load range and fast start up and cold down	% sec	5-100 600		load range is 5 to 120 % for PEMEL, 15 to 110% for AWEL or 30 to 125 % for SOEL and the start up and cold down time ranges from <60 seconds for PEMEL to >10 h for SOEL	2020
	Able to operate with direct electrolysis of wastewater	-	yes		N/A	N/A
	Potential cost production of below 3 €/kg H_2.	€/kg	3		Supercritical electrolysis has production cost about 7.5 $/kg H_2. With CAPEX, cost of electricity, etc. optimized, is expected to achieve 3.10 $/kg H_2 while AWEL and PEMEL are expected to produce H_2 at 4.0 - 4.5 $/kg H_2	2021
	1 LCA containing circularity + 1 s-LCA + 1 LCC of the X-SEED electrolyser	Number of studies	3		N/A	N/A
	Reduction of electricity consumption in comparison to AWEL and PEMEL, considering electrolysers powered by electrical grid	% of $kgCO_2$ eq reduction respect AWEL and PEMEL	20		Carbon footprint is influenced by carbon footprint of electricity used; it varies from 25 $KgCO_2/kg\ H_2$ (for AWEL and SOEL) to 20 $KgCO_2/kg\ H_2$ for SOEC, considering grid electricity Germany 2018 (0.47 tn CO_2/MWh)	2020
	Non-use Pt, Ru, decrease use of CRM	mg/W	<0.3		0 m g of CRM/W	2021
	Feedback received from experts through one workshop or participatory activity, as part of the social assessment	Number of feedback	>15		N/A	N/A
	Recovery > 50 % of internal heat and demonstrate the feasibility of meeting over 30% of the system's heat demand by utilising industrial waste heat	% of heat recovered	50			
	Contributions in peer reviewed open access articles and conference	Number	22			
	Patents	Number	2			
	Expand the use of renewable H_2 technology among existing and potential end users	Number	5			
	External interactions through social media, workshops, and disclosure articles	Number	5 000			
	Synthesise and study of different classes of catalysts (perovskites, metal oxides and transition metal decorated nanoparticles)	Types of catalyst	3	✓		

Clean Hydrogen Partnership
Co-funded by the European Union