ADVANCEPEM

ADVANCED HIGH PRESSURE AND COST-EFFECTIVE PEM WATER ELECTROLYSIS TECHNOLOGY

Project ID	101101318
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	HORIZON-JTI-CLEANH2-2022-01-03: Development of low temperature water electrolysers for highly pressurised hydrogen production
Project total costs	EUR 1 631 066.56
Clean H_2 JU max. contribution	EUR 1 607 330.00
Project period	1.2.2023–31.1.2026
Coordinator	Consiglio Nazionale delle Ricerche, Italy
Beneficiaries	HSSMI Trading Limited, IRD Fuel Cells A/S, OORT Energy Ltd, Rhodia Laboratoire du Futur, Rhodia Operations, RWE Generation SE, RWE Power AG, Solvay Specialty Polymers Italy SpA

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 downstream gas compression. Advancepem aims to develop a set of breakthrough solutions at the 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 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 AND MAIN ACHIEVEMENTS

Functional components have been developed and stack development activities have been addressed.

The plan for validation of the PEM electrolyser is in place. The most important technical, health, safety and environmental standards, technical parameters and boundary conditions have been defined with regard to the installation, commissioning and testing of newly developed technology.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objectives and AWP 2022	Cold start ramp time	seconds	10	N/A	⚙
	Degradation	%/1 000 h	0.25	N/A	
	Capital cost referred to input power	€/kW	500	N/A	
	Current density	A/cm²	5	N/A	
	Hot idle ramp time	seconds	1	N/A	
	Capital cost referred to capacity	€/(kg/day)	1 000	N/A	
	Low electrode overpotentials	mV	200	120	✓
	Electricity consumption @ nominal capacity	kWh/kg	50	N/A	⚙
	Hydrogen output pressure	bar	200	N/A	
	Membrane conductivity	mS/cm	200	> 200	✓
	Use of critical raw materials as catalysts	mg/W	43	N/A	⚙
	O&M cost	€/(kg/day)/year	30	N/A	
	Stack operating temperature	°C	80–90	N/A	
	Cell performance	V @ 5 A/cm²	1.85	1.83	✓

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AEMELIA

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

Project ID	101137912
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	HORIZON-JTI-CLEANH2-2023-01-01: Innovative electrolysis cells for hydrogen production
Project total costs	EUR 2 764 927.00
Clean H_2 JU max. contribution	EUR 2 764 926.75
Project period	1.1.2024–28.2.2027
Coordinator	Commissariat à l'énergie atomique et aux énergies alternatives, France
Beneficiaries	Centre national de la recherche scientifique, Claind SRL, Consiglio Nazionale delle Ricerche, Fundacion Tecnalia Research and Innovation, Imperial College of Science, Technology and Medicine, Matgenix, Rhodia Laboratoire du Futur, SINTEF AS, Solvay Specialty Polymers Italy SpA, Specialty Operations France

https://cordis.europa.eu/project/id/101137912

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 proposes a clear path to reach a high current density (1.5 A/cm²) at low voltage (1.72 V). Energy efficiency surpasses the 2030 target (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/cm² in 0.2 M KOH at 42 °C and 10 bar). The levelised cost of hydrogen also outshines the 2030 targets at EUR 2.5/kg H_2 (17 % lower than the 2030 target). The degradation rate meets the 2030 target, enabling a 10-year lifetime. Capital expenditure is slightly higher, according to preliminary estimations, but upscaling is expected to reduce this to the 2030 strategic research and innovation agenda (SRIA) target.

Aemelia brings together leading European AEMEL experts and manufacturers to meet key performance indicators, most importantly to deliver an electrolysis stack that can operate at a high current density (1.5 A/cm²) at a low voltage (1.72 V). This very high current density triples the hydrogen production per kWh achieved by the state of the art (SOA) at 0.5 A/cm².

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?	SOA result achieved to date (by others)
SRIA (2021–2027)	Degradation	%/1 000 h	0.5 %/1 000 h @ 1.5 A/cm², tested for 2 000 hours		0.9 SRIA target for 2024 / 8-year lifetime for CLD AEMEL and 4-year lifetime for Enapter AEMEL
	Use of CRM as catalysts	mg/W	0		Dioxide Materials' commercial electrodes: 1.85 V @ 1 A/cm² in 1 M KOH with a cathode made of 2 mg/cm² of NiFeCo on a 25 cm² electrode 0.4 SRIA target for 2024
	Electricity consumption @ nominal capacity	kWh/kg	46.2		53.3
	LCOH	€/kg	2.5		2030 SRIA target of €3/kg
	Current density	A/cm²	1.5		1.0 in 1 M KOH (60 °C)
	CAPEX	€/kW	321		Benchmark is 2024 SRIA target of €550/kW

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ANIONE

ANION EXCHANGE MEMBRANE ELECTROLYSIS FOR RENEWABLE HYDROGEN PRODUCTION ON A WIDE-SCALE

Project ID	875024
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	FCH-02-4-2019: New anion exchange membrane electrolysers
Project total costs	EUR 1 999 995.00
Clean H_2 JU max. contribution	EUR 1 999 995.00
Project period	1.1.2020–30.9.2023
Coordinator	Consiglio Nazionale delle Ricerche, Italy
Beneficiaries	Hydrolite Ltd, Université de Montpellier, TFP Hydrogen Products Ltd, Hydrogenics Europe NV, IRD Fuel Cells A/S, Uniresearch BV, Centre national de la recherche scientifique

https://anione.eu/

PROJECT AND GENERAL OBJECTIVES

The Anione project's primary goal was to create a high-performance, cost-effective and durable anion-exchange membrane water electrolysis (AEMWE) technology. This technology integrates anion-exchange membrane (AEM) and ionomer dispersion in catalytic layers for hydroxide ion conduction, combining the benefits of proton-exchange membrane and liquid electrolyte alkaline technologies. This approach facilitates the scalable production of low-cost hydrogen from renewable sources.

The project focused on developing hydrocarbon AEM membranes with either poly(arylene) or poly(olefin) backbones, incorporating quaternary ammonium hydroxide groups anchored to the polymer backbone. Concurrently, advanced short-side-chain Aquivion®-based AEMs with perfluorinated backbones and quaternary ammonium groups were developed. The goal was to match the conductivity and stability of these AEMs with their protonic counterparts and to improve mechanical stability and reduce gas crossover using novel nanofibre reinforcements.

NON-QUANTITATIVE OBJECTIVES

- **Enhanced oxygen evolution catalysts.** Development of an advanced, non-critical-raw-material, NiFe-based catalyst for the oxygen evolution reaction with reduced overpotential and enhanced stability.
- **Enhanced hydrogen evolution catalyst.** Development of an advanced, non-critical-raw-material, Ni-based catalyst for the hydrogen evolution reaction with reduced overpotential and enhanced stability
- **Advanced cost-effective membrane.** Development of cost-effective advanced AEMs with proper hydroxide ion conductivity and stability.
- **Process implementation.** Development of an AEM electrolysis operating mode with enhanced stability.
- **AEM electrolysis hardware components.** Implementation of advanced AEM electrolysis components in terms of diffusion layers and current collectors.
- **AEM electrolysis stack.** Development of an advanced, non-critical raw material AEM electrolysis stack.

PROGRESS AND MAIN ACHIEVEMENTS

The work addressed AEMWE technology development. The main results are summarised below.

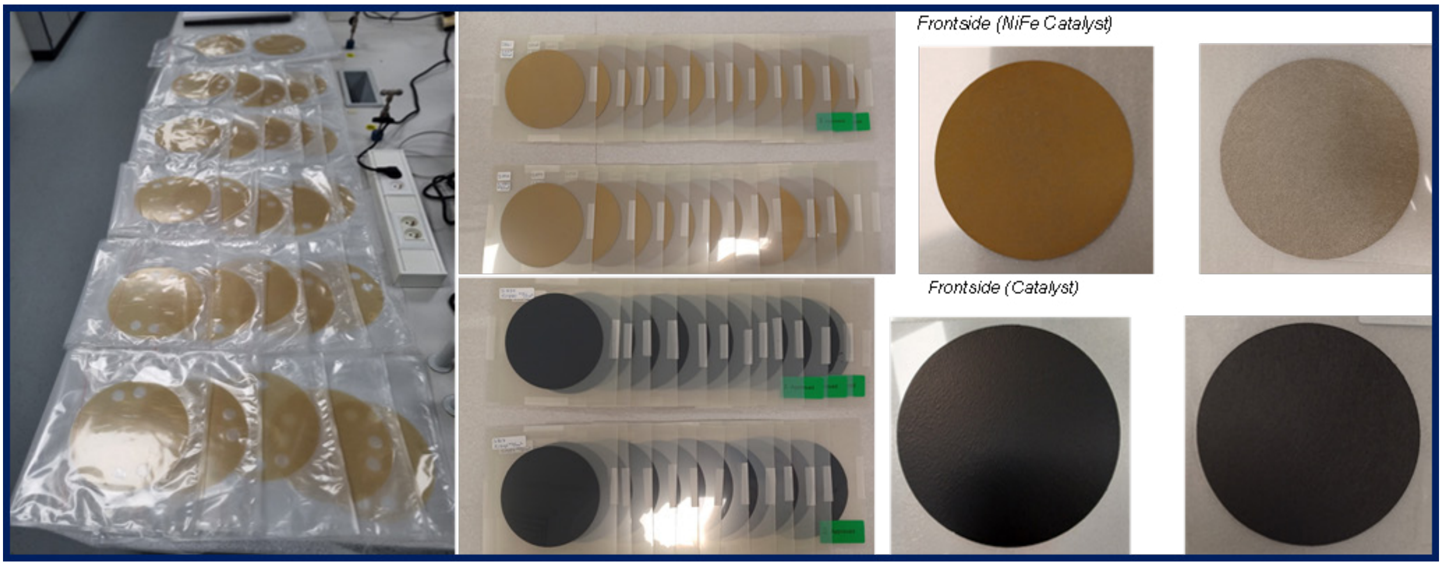
- Fluorinated and hydrocarbon AEM ionomers with quaternary ammonium functional groups were developed and characterised in terms of ion-exchange capacity and anion conductivity.
- A nanosized NiFe-oxide, oxygen evolution anode electrocatalyst and a carbon-supported, Ni-based, hydrogen evolution cathode electrocatalyst for AEMWE were developed.
- Membrane electrode assemblies based on catalyst-coated electrodes including the nanosized, Ni-based anode and cathode electrocatalysts have shown electrolysis performance of about 1.8 V at 1 A/cm^2 and 50 °C. Stable performance were observed during 2 000-hour steady-state and 1 000-hour cycled (0.2–1 A/cm^2) operations.
- Large-area (> 100/cm^2) membrane electrode assemblies were integrated into a simplified stack design.
- The novel solutions developed in the project were validated in an AEM electrolysis stack of 2 kW capacity with a hydrogen production rate of about 0.4 Nm^3/h (technology readiness level 4) with 57 kWh/kg H_2 energy consumption at 1 A/cm^2. A second stack was assembled and showed improved durability, with continuous increase in its performance over time.
- A single-cell performance of 1 A/cm^2 at about 1.8 V/cell was achieved using non-critical raw materials and hydrocarbon membranes.
- A 2 kW AEM electrolyser, achieving a hydrogen production rate of about 0.4 Nm^3/h (technology readiness level 4), was validated as a proof of concept.

FUTURE STEPS AND PLANS

The project has finished

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
AWP 2019	Maximum operating temperature	°C	90	90	✓	60	2022
	Series resistance	ohm cm^2	< 0.07	0.06	✓	0.1	2022
	Degradation rate: voltage increase at 1 A/cm^2	mV/h	< 0.005	< 0.005	✓	2	2020
	Electrolysis CAPEX @ the system level	M €/(t/day)	0.75	N/A	⚙	1.6	2020
	AEMWE stack efficiency	%	70	70	✓	N/A	N/A
	AEMWE stack power	kW	2	2.1	✓	N/A	N/A
	AEMWE stack capacity	kg/day	0.8	0.87	✓	N/A	N/A
	Membrane conductivity	mS/cm	50	105	✓	80	2022
	Cell voltage at 1 A/cm^2 (cell performance at 45 °C)	V	2	1.75	✓	1.67	2020

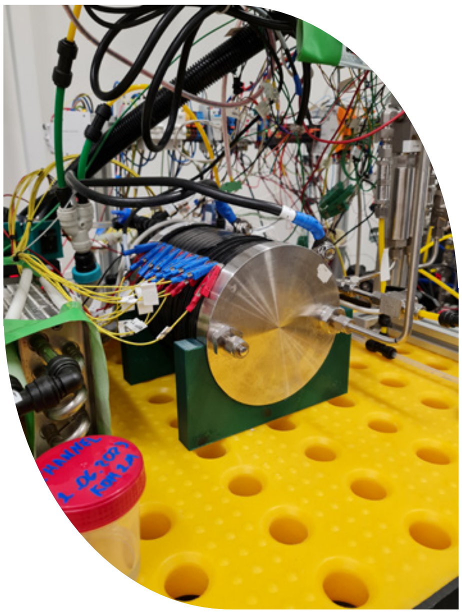


CHANNEL

DEVELOPMENT OF THE MOST COST-EFFICIENT HYDROGEN PRODUCTION UNIT BASED ON ANION EXCHANGE MEMBRANE ELECTROLYSIS

Project ID	875088
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	FCH-02-4-2019: New anion exchange membrane electrolysers
Project total costs	EUR 1 999 906.25
Clean H_2 JU max. contribution	EUR 1 999 906.25
Project period	1.1.2020–30.6.2023
Coordinator	SINTEF AS, Norway
Beneficiaries	Enapter SRL, Evonik Creavis GmbH, Evonik Operations GmbH, Forschungszentrum Jülich GmbH, Norges teknisk-naturvitenskapelige universitet, Shell Global Solutions International BV

https://www.sintef.no/projectweb/channel-fch/



PROJECT AND GENERAL OBJECTIVES

The EU-funded project Channel aimed to develop a cost-efficient 2 kW water electrolyser stack based on the emerging anion-exchange membrane electrolysis (AEMEL) technology for producing high-quality, low-cost green hydrogen from renewable energy sources. This project's aim included the development of stack components ranging from the non-platinum-group-metal-based electrocatalysts to the balance of plant. The Channel project had as its objectives the (i) optimisation and utilisation of advanced anion-exchange membranes (AEMs) and ionomers, (ii) development of cost-efficient and stable catalysts for high-performance electrodes, (iii) development of system models to help guide the stack design and integration of components into the stack and to aid the design of the balance of plant and (iv) market analysis and cost and performance assessment based on the experimental results of the Channel 2 kW stack prototype.

NON-QUANTITATIVE OBJECTIVES

- Promotion of the AEMEL technology by organising technical workshops and contributing to science and technology through publications and participations in conferences.
- Establishment of the AEM-Hub – Reshaping Green Hydrogen Production, together with Newely and Anione.
- Release of the transient AEM model code on the public platform Github.

PROGRESS AND MAIN ACHIEVEMENTS

- Channel successfully developed alternative low-cost non-platinum-group-metal catalysts for hydrogen evolution reaction (HER) and oxygen evolution reaction (OER) using simple and scalable synthesis methods. The electrocatalysts were synthesised by combining materials such as nickel, iron and molybdenum in an optimal composition and structure so that they exhibited comparable performance and stability to those of the precious metals, demonstrating that switching to non-precious-metal electrodes is a promising route for AEMEL.
- The Ni-based HER catalyst achieves Channel's performance and stability targets at less than 1 M KOH (– 10 mA/cm^2 at < 100 mV overpotential in 0.5 M KOH) with excellent batch-to-batch reproducibility. The catalyst showed an outstanding 1000 hours of stability in chronoamperometry measurements and displayed only 26 μV/h in chronopotentiometry mode. The Ni-based OER catalyst also achieved Channel's performance and stability targets at less than 1 M KOH (10 mA/cm^2 at < 300 mV overpotential). The catalyst presented excellent stability in chronoamperometry measurement for more than 500 hours.
- A joint test protocol for single-cell electrolysis measurements was developed. Single-cell testing performed in different set-ups showed significant differences due to differing hardware. The optimised membranes and electrodes reached the single-cell performance target of 1 A/cm^2 at 1.85 V. A long-term test of more than 1 000 hours at 1 A/cm^2 showed good stability of all components.
- Contribution to the AEM test protocol harmonisation workshop alongside NEWELY and ANIONE.

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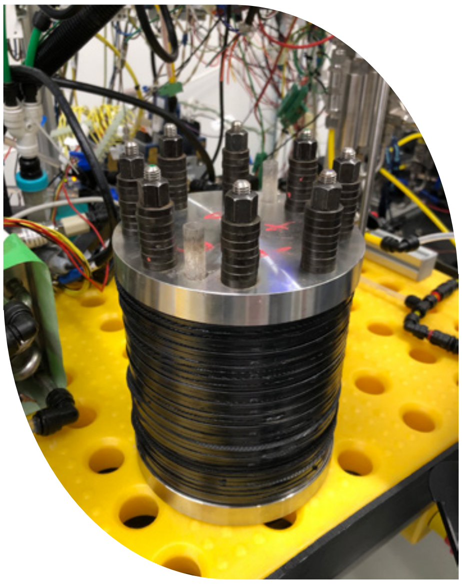
CHANNEL



FUTURE STEPS AND PLANS

The project has finished, with further opportunities having been identified.

- Although Channel achieved optimised electrodes and membranes that reached the performance target of 1 A/cm^2 at 1.85 V (single-cell tests) with good stability of all components in a long-term test of more than 1 000 hours at 1 A/cm^2, a lot of effort is needed to translate the idealised testing system at the lab scale into real stack operation. The lower-than-expected stack performance achieved evidenced that more time is required to transfer and optimise the integration of lab-scale developments for the industrial level. However, this does not mean that stack performance is not achievable. The projected cost analysis showed that capital expenditure of < EUR 600/kW at a 500 kW system scale is possible based on the Channel AEMEL stack technology. When all the technical targets are met and desirable stack performance is achieved, partners will exploit the technology and create new market opportunities, both inside and outside Europe, which will create new job opportunities.
- In addition, a computational model of AEMEL was developed, which was used to simulate the cell performance and lifetime under varying operational scenarios. The model achieved a reasonably good fit to the experimental data, particularly within the large ohmic region above about 0.5 A/cm^2. Efforts are still needed to improve the performance of the model in the kinetic region by refining the electrochemical kinetic submodel used in the catalyst layer.

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	OER catalyst stability	mV	< 25 mV degradation over 1 000 hours in RDE	33	⚙	N/A	N/A
	Single-cell performance (at 1 A/cm^2)	V	1.85	1.85	✓	1.85	2023
	OER catalyst performance	mV	< 300 mV (at 10 mA/cm^2) in 1 M KOH	237 mV (1 M KOH) 270 mV (0.1 M KOH)	✓	Ir-based catalyst (250 mV at 10 mA/cm^2)	2023
	HER catalyst performance	mV	< 150 mV (at 10 mA/cm^2) in < 1 M KOH	60 mV in 1 M KOH, 120 mV in 0.1 M KOH at 10 mA/cm^2	✓	Pt-based catalyst (30 mV at − 10 mA/cm^2) in 1 M KOH	2023
	HER catalyst stability	mV	< 25 mV degradation over 1 000 hours in RDE	26 mV/1000 h, 3 µA/h at − 0.2 V (RHE)	⚙	N/A	N/A
AWP 2019	Membrane OH^- conductivity (RT and 60 °C)	mS/cm	RT: > 50 60 °C: > 90	RT: > 50 60 °C: 95–105	✓	~ 120 (50-micron membrane from Sustainion) 40–45 mS/cm FAA-3 (Fumatech)	2023
	Ionomer OH conductivity (60 °C)	mS/cm	Not specified	> 60	✓	N/A	N/A

DEMO4GRID

DEMONSTRATION OF 4MW PRESSURIZED ALKALINE ELECTROLYSER FOR GRID BALANCING SERVICES

Project ID	736351
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	FCH-02-7-2016: Demonstration of large-scale rapid response electrolysis to provide grid balancing services and to supply hydrogen markets
Project total costs	EUR 7 736 682.50
Clean H_2 JU max. contribution	EUR 2 932 554.38
Project period	1.3.2017–31.8.2023
Coordinator	Diadikasia Business Consulting Symvouloi Epicheiriseon AE, Greece
Beneficiaries	FEN Sustain Systems GmbH, Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón, IHT Industrie Haute Technologie SA, Instrumentación y Componentes SA, MPREIS Warenvertriebs GmbH

www.demo4grid.eu/

PROJECT AND GENERAL OBJECTIVES

The main aim of project Demo4grid was the commercial set-up and demonstration of a technical solution utilising pressurised alkaline electrolyser technology that is better than the state of the art to provide grid-balancing services in real operational and market conditions. The final goal was to provide grid-balancing services to the transmission system operator (primary and secondary balancing services). The electrolysis plant was installed in Völs near Innsbruck.

PROGRESS AND MAIN ACHIEVEMENTS

The pressurised alkaline electrolyser was installed and has been producing hydrogen since 22 March 2022.

FUTURE STEPS AND PLANS

The project has finished.

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	H_2 production electrolysis, hot start from minimum to maximum power	seconds	2	N/A	⚙	60	2015
	Start-up time KPIs from cold to minimum part load for alkaline electrolysers	minutes	20	4–6 hours depending on thermal conditions		30	2015
	Ramp down	% (full load)/s	10	2		10	N/A
	Minimum part-load operation targets for alkaline electrolysers	% (full load)	20	N/A		30	2015
	Ramp up	% (full load)/s	7	3		7	N/A

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DJEWELS

DELFZIJL JOINT DEVELOPMENT OF GREEN WATER ELECTROLYSIS AT LARGE SCALE

Project ID	826089
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	FCH-02-1-2018: Demonstration of a large scale (min. 20 MW) electrolyser for converting renewable energy to hydrogen
Project total costs	EUR 41 967 250.00
Clean H_2 JU max. contribution	EUR 10 999 999.00
Project period	1.1.2020–31.12.2025
Coordinator	Hydrogen Chemical Company BV, Netherlands
Beneficiaries	BioMethanol Chemie Nederland BV, Hinicio, Industrie De Nora SpA, McPhy Energy, McPhy Energy Deutschland GmbH, McPhy Energy Italia SRL, Nobian Industrial Chemicals BV, NV Nederlandse Gasunie

https://djewels.eu

PROJECT AND GENERAL OBJECTIVES

Djewels demonstrates the operational readiness of a 20 MW electrolyser for the production of green fuels (green methanol) in real-life industrial and commercial conditions. It will bring the technology from technology readiness level 7 to 8 and lay the foundation for the next scale-up step: a 100 MW electrolyser 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 for the serial manufacturing of the stack and scale-up of the balance-of-plant components.

NON-QUANTITATIVE OBJECTIVES

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

PROGRESS AND MAIN ACHIEVEMENTS

- Finalisation of the Djewels 1 design.
- Issuing of irrevocable permits.
- Completed testing of the 1 MW stack.

FUTURE STEPS AND PLANS

- Stack testing and optimisation is to be finished. This is delayed, and was expected to be completed in July 2022.
- The investment decision is expected to be made in quarter 3 of 2024.
- Ground breaking is expected to take place in quarter 4 of 2024.
- Construction is expected to be completed in 2026.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	System nominal capacity	MW	25	(in progress)
	Electrolysis CAPEX @ rated power, including ancillary equipment and commissioning	M €/(t/day)	5.5	
AWP 2018	Flexibility with degradation below 2 %/year	% of nominal power	3–110	(in progress)
	Energy consumption	kWh/kg	< 52.8	(in progress)
	Degradation	%/year	0.72	(in progress)

ENDURE

ALKALINE ELECTROLYSERS WITH ENHANCED DURABILITY

Project ID	101137925
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	HORIZON-JTI-CLEANH2-2023-01-03: Advances in alkaline electrolysis technology
Project total costs	EUR 2 492 868.75
Clean H_2 JU max. contribution	EUR 2 492 868.75
Project period	1.1.2024–31.12.2026
Coordinator	Stargate Hydrogen Solutions OÜ, Estonia
Beneficiaries	Fraunhofer Gesellschaft zur Förderung der angewandten Forschung EV, Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón, Permascand AB, Université catholique de Louvain, Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg

https://www.endureh2.com/

PROJECT AND GENERAL OBJECTIVES

The main objective of the Endure project is to bring the performance and durability of alkaline electrolysers to a new level. More specifically, it aims 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; design/material improvements at the stack level; and accelerated testing procedures.

If the electrolyser degradation rate could be reduced, it would result in twofold benefits:

- lower operating expenditure through lower energy consumption over an electrolyser's 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.

NON-QUANTITATIVE OBJECTIVES

Endure aims to make the alkaline electrolysers more durable – that is, it aims to drastically decrease the degradation rate of alkaline electrolysis cells and stacks 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 AND MAIN ACHIEVEMENTS

The Endure project will result in an innovative electrolyser stack design with innovative technological components. Endure will yield higher electrolyser durability thanks to the decreased degradation rate of alkaline electrolysis cells and stacks through electrode improvements, design and material innovation at the stack level and through the development of accelerated testing procedures. By the end of the project, the subcomponents and the short stack of at least five cells will be tested, validated and demonstrated at the lab scale.

FUTURE STEPS AND PLANS

- Develop and provide a 10 kW short stack with Ni foam electrodes.
- Adopt a report on harmonised test protocols for Endure.
- Mount a stack in the test bench.
- Get input for 3D meshing for microscale computer simulations.
- Get the diaphragm test results under nominal and part loads.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Stack durability data (cell voltage versus time at a fixed current density)	-	Two alkaline stacks (baseline and improved) tested for 500 hours at constant load	
SRIA (2021–2027)	Use of critical raw materials as catalysts	mg/W	0	
	O&M cost	€/(kg/day)/year	35	
	Current density	A/cm²	> 1.25	
	CAPEX	€/kW	150	
	Electricity consumption @ nominal capacity	kWh/kg	< 48	
	Degradation rate	%/1 000 h	< 0.1	

EPHYRA

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

Ephyra

Project ID	101112220
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	HORIZON-JTI-CLEANH2-2022-01-08: Integration of multi-MW electrolysers in industrial applications
Project total costs	EUR 24 631 840.00
Clean H_2 JU max. contribution	EUR 17 757 002.50
Project period	1.6.2023–31.5.2028
Coordinator	Motor Oil (Hellas) Diilistiria Korinthou AE, Greece
Beneficiaries	Deutsches Zentrum für Luft- und Raumfahrt EV, Enertime SA, Envirometrics Technikoi Symvouloi Etaireia Periorismenis Efthynis, Ethniko Kentro Erevnas Kai Technologikis Anaptyxis, Instituto Tecnológico de Aragón, RINA Consulting SpA, Siemens Process Systems Engineering Ltd, Soluforce BV, Stichting New Energy Coalition

https://ephyraproject.eu/

PROJECT AND GENERAL OBJECTIVES

Ephyra will demonstrate the integration of a first-of-its-kind renewable hydrogen production facility at the industrial scale in south-eastern Europe by employing an improved electrolysis technology at a scale of 30 MW. The large-scale electrolysis technology 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 2 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) environmental optimisation of water use, (iv) valorisation of produced oxygen in Motor Oil Hellas's current 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, the project will demonstrate the technology's reliability for green hydrogen production at the lowest possible cost, thus enabling the EU's 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 the synergies among H_2 production – use – complementary supply and the valorisation of waste streams (waste heat, oxygen, water) under the circular economy approach.
- 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.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objective	Capital cost	€/kW	≤ 480 ± 10 %	
Project's own objective	O_2 production (base case)	t/year	19 322	
Project's own objective	Current density	A/cm²	> 0.6	
Project's own objective	Electricity consumption @ nominal capacity	kWh/kg	≤ 49	
Project's own objective	Operating hours per year (base case)	h/year	3 945	
Project's own objective	O_2 production (full load)	t/year	39 184	
Project's own objective	Cold start ramp time	seconds	≤ 900	
Project's own objective	CO_2 savings for project duration (base case)	kt/year	52.6	
Project's own objective	O&M cost	€/(kg/day)/year	≤ 43 ± 10 %	
Project's own objective	Availability (full load)	%	91	
Project's own objective	Degradation	%/1 000 h	≤ 0.11	
Project's own objective	H_2 production (full load)	t/year	4 898	
Project's own objective	H_2 production (base case)	t/year	2 415	
Project's own objective	CO_2 savings for project duration (full load)	kt/year	108.1	
Project's own objective	LCOH targeted (full load)	€/kg H_2	2.6	
Project's own objective	LCOH targeted (base case)	€/kg H_2	3.3	
Project's own objective	Use of critical raw materials as catalysts	mg/W	< 0.6	
Project's own objective	Availability (base case)	%	45	
Project's own objective	Hot idle ramp time	seconds	≤ 30	
Project's own objective	Operating hours per year (full load)	h/year	8 000	

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EXSOTHYC

EXSOLUTION-BASED NANOPARTICLES FOR LOWEST COST GREEN HYDROGEN VIA ELECTROLYSIS

Project ID	101137604
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	HORIZON-JTI-CLEANH2-2023-01-01: Innovative electrolysis cells for hydrogen production
Project total costs	EUR 2 495 480.00
Clean H_2 JU max. contribution	EUR 2 495 480.00
Project period	1.1.2024–31.12.2026
Coordinator	Stargate Hydrogen Solutions OÜ, Estonia
Beneficiaries	Agfa-Gevaert NV, Fraunhofer Gesellschaft zur Förderung der angewandten Forschung EV, Technische Universiteit Eindhoven, The University Court of the University of St Andrews

https://cordis.europa.eu/project/id/101137604

PROJECT AND GENERAL OBJECTIVES

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

NON-QUANTITATIVE OBJECTIVES

The project aims to contribute to scientific advances across and within various disciplines, such as 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 the lower price, and the growth of the renewable energy sector.

The project also aims to help achieve the Green Deal goals, sustainable energy production, energy security, no CO_2 emissions, cleaner air, a lower environmental impact due to not using platinum group metals and the creation of more green jobs.

PROGRESS AND MAIN ACHIEVEMENTS

The Exsothyc project will optimise electrolyser operation, moving towards lower voltages and higher efficiencies. Within the project, a breakthrough concept for catalyst materials and for cell and stack components for alkaline electrolysers will be developed. A class of ceramic materials that form highly active metallic nanoparticles on the surface when exposed to a reducing atmosphere (a process called 'exsolution') plays a central role in the project.

FUTURE STEPS AND PLANS

- Select recombination catalysts (and their supply) for alkaline water electrolysis.
- Define the catalyst-coated diaphragms (CCD) approach for Zirfon material with optimal binder/catalyst choice, thus determining a benchmark for CCDs.
- Provide risk analysis and a safety-planning strategy.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
SRIA (2021–2027)	H_2 concentration in O_2 at 5 % of nominal operating point of 0.5 A/cm^2	%	0.4	
	Capital cost	€/(kg/day)	-	
	Capital cost	€/kW	The value will be provided by M24	
	Use of critical raw materials (as defined in the SRIA) as catalysts	mg/W	< 0.3 for alkaline cells and 0.0 for novel materials	
	Interface resistance across cell components, expressed as decrease in cell potential between the CCD and the CCS cells	V	Cell potential decrease by ≥ 0.3 V compared with the CCS cells	
	Electricity consumption @ nominal capacity	kWh/kg	48	
	Current density operation (i.e. 1.0)	A/cm^2	1	
Project's own objectives	Long-term, stable and efficient materials for high-current-density operation (1.0 A/cm^2), expressed as average electricity consumption during nominal operation during 500 hours of testing	kWh/kg	48	

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HAEOLUS

HYDROGEN-AEOLIC ENERGY WITH OPTIMISED ELECTROLYSERS UPSTREAM OF SUBSTATION

Project ID	779469
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	FCH-02-4-2017: Highly flexible electrolysers balancing the energy output inside the fence of a wind park
Project total costs	EUR 7 779 761.25
Clean H_2 JU max. contribution	EUR 4 997 738.63
Project period	1.1.2018–31.12.2023
Coordinator	SINTEF AS, Norway
Beneficiaries	Communauté d'universités et d'établissements université Bourgogne–Franche–Comté, Ecole Nationale Superieure de Mécanique et des Microtechniques, Fundacion Tecnalia Research and Innovation, Hydrogenics Europe NV, Knowledge Environment Security SRL, Stiftelsen SINTEF, Università degli Studi del Sannio, Université de Franche-Comté, Université de technologie de Belfort-Montbéliard, Varanger Kraft AS, Varanger KraftEnterprenør AS, Varanger KraftHydrogen AS, Varanger KraftMarked AS, Varanger KraftNett AS, Varanger KraftVind AS, Varanger KraftUtvikling AS

http://www.haeolus.eu/

PROJECT AND GENERAL OBJECTIVES

The project deployed a 1 t/day electrolyser in the remote village of Berlevåg in Norway, together with a storage tank and fuel cells for re-electrification, in connection with a wind farm. The objective was to test the operation of the electrolyser in different scenarios to demonstrate algorithms for energy storage, isolated grid operation and fuel production.

NON-QUANTITATIVE OBJECTIVES

The objective was to promote the hydrogen valley in Finnmark. Local authorities and business stakeholders are very interested in the project. Varanger Kraft has decided to proceed with building a distribution station, and local actors are involved in multiple multi-million-euro research and innovation proposals for further development.

PROGRESS AND MAIN ACHIEVEMENTS

The plant has been installed and is operative, and Varanger Kraft has started building a hydrogen refuelling station around it. An analysis of the operational conditions placed the cost of hydrogen production from the Raggovidda wind farm at between EUR 4/kg and EUR 6/kg, which is a competitive level. The project developed and published control strategies based on advanced model-predictive controllers that continuously re-optimise operation based on the best data available at the moment; these were tested by simulations fed with real-life data.

FUTURE STEPS AND PLANS

The project has finished.

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	CAPEX	M €/(t/day)	3	2.3	✓	1.5–3.3	2020
MAWP addendum (2018–2020)	Efficiency	kWh/kg	52	53.8	✓	55	2021
	Degradation	%/year	1.5	2	⚙	N/A	N/A
	Cold start	minutes	0.5	20	⚙	N/A	N/A
	Hot start	seconds	2	30	⚙	N/A	N/A

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 2024	Pillar 1 – Renewable hydrogen production
Call topic	HORIZON-JTI-CLEANH2-2022-01-04: Design for advanced and scalable manufacturing of electrolysers
Project total costs	EUR 2 342 385.00
Clean H_2 JU max. contribution	EUR 1 999 622.50
Project period	1.6.2023–31.5.2027
Coordinator	Schaeffler Technologies AG & Co. KG, Germany
Beneficiaries	Consiglio Nazionale delle Ricerche, Exentis Technology GmbH, HyGear BV, HyGear Fuel Cell Systems BV, HyGear Hydrogen Plant BV, HyGear Operations BV, HyGear Technology and Services BV, John Cockerill Hydrogen Belgium, Manufacture Française des Pneumatiques Michelin, Monolithos Katalites Ke Anakiklosi Etaireia Periorismenis Evthinis, Vlaamse Instelling voor Technologisch Onderzoek NV

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

PROJECT AND GENERAL OBJECTIVES

The project aims are as follows.

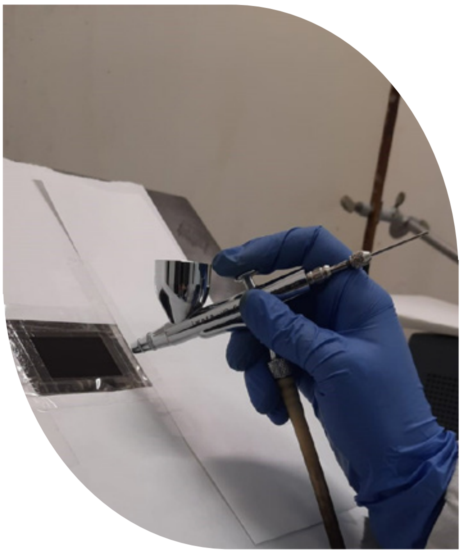
- Heraqcles will develop automated manufacturing processes for anion-exchange membrane (AEM) water electrolysers and validate a proof-of-concept 25 kW system operating at 30–50 bar with a hydrogen production rate of about 12.5 kg H_2/day (manufacturing readiness level 5) with detailed design and cost calculation for a 100 MW electrolysis plant.
- The project will produce a marked increase in operating current density (1 A/cm^2 nominal at 1.8 V/cell and 2 A/cm^2 at 2.2 V) while keeping energy consumption to < 48 kWh/kg at 1 A/cm^2 with a stack efficiency of ~ 80 % in respect of the higher heating value (~ 70 % in respect of the 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 a much higher current density.
- It will also reduce the capital costs in large-scale production (100 MW production volume) to less than EUR 0.6 million/(t/day H_2). This corresponds to EUR 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 material use, a simplified balance of plant for differential pressure operation and the increased current density (according to Faraday's law) will bring a new perspective.
- Heraqcles aims to validate the durability under steady and intermittent duty cycle 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 a targeted degradation rate of less than 5–7 μV/h at a fixed current density of 1 A/cm^2, corresponding to about 0.2–0.4 %/1 000 h.
- The system will operate for 10 years without stack replacement and 20 years with a single stack replacement (cut-off voltage: 2.4 V).
- The project will achieve a significant reduction in the levelised cost of hydrogen to less than EUR 2–3/kg H_2, with EUR 0.6 million/(t/day H_2) in capital expenditure, and operation and maintenance costs of less than EUR 20/(kg/day)/year, assuming a EUR 40/MWh renewable electricity cost and 4 000 h/year of uptime.
- It will also achieve market competitiveness for green hydrogen.

NON-QUANTITATIVE OBJECTIVES

The Heraqcles project 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. The project will thus contribute to EU policy in terms of limiting the environmental impact of current hydrogen technology applications, minimising material usage, avoiding critical raw materials (CRMs), improving the cost-effectiveness of clean hydrogen solutions and reinforcing the EU's scientific and industrial ecosystem.

PROGRESS AND MAIN ACHIEVEMENTS

- Project management procedures have been installed, such as an administrative toolset, a data management plan and a detailed risk management plan.
- Monolithos has received spent AEM and proton-exchange membrane water electrolyser membrane electrode assemblies – with CRM (Pt and Ir) and non-CRM (Ni, Fe and Mo) electrodes – from Schaeffler and Consiglio Nazionale delle Ricerche. In addition, life-cycle analysis studies have been undertaken



to evaluate the environmental impact of the process, identify areas of high environmental impact and explore alternative options for reducing energy consumption, CO_2 emissions and waste generation.

- State of the art from scientific and technical sources enables the selection of the best protocols for AEM materials and membrane testing. In terms of experimental work, equipment tool build-up is in progress. Regarding AEM material, formulations have been selected using an experimental design approach and the preliminary test casting of liquid formulations has started.
- The project has developed NiFe layered double hydroxide anode electrocatalysts (BET, 116 m^2/g; XRF, 85:15 at. %; XRD, PS = 5 nm), developed 40 % Ni0.8Mo0.2/C cathode electrocatalysts (XRF, 80:20 at. %; XRD, PS = 10 nm), developed printing pastes (316L) with pore-forming agents, designed printing screens according to a defined geometry co-designed with Schaeffler and printed the first samples (316L), tested the debinding of the developed pastes and completed the first sintering trial. Samples are now being studied in terms of the achieved material properties, such as porosity, and successful debinding of all carbon.
- Heraqcles has designed loops to adapt the existing polymer electrolyte membrane platform to AEM technology, aligned the components and tested the rig design according to the stack specification.
- The development of a system for protype stack testing is in the early stages of the engineering phase. The process flow diagram has been created, and a start has been made on the mass and energy balance.
- The project identity, logo, flyer and website have been finished for communication activities. A communication, exploitation and dissemination plan has been made and uploaded.

FUTURE STEPS AND PLANS

Heraqcles will complete the assembly and testing of the loop 1 stack.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives and SRIA (2021–2027)	CAPEX	€/kW	300	
SRIA (2021–2027)	Degradation	%/1 000 h	0.4	
	Electricity consumption @ nominal capacity	kWh/kg	48 kWh/kg @ 1 A/cm^2	
	Current density	A/cm^2	1	
	O&M cost	€/(kg/day)/year	20	
	Voltage	V	1.8 V/cell at 1 A/cm^2 current density	
	Hydrogen cost	€/kg	2–3	
	Capital cost	€/(kg/day)	600	
	Use of CRMs as catalysts	mg/W	0	

HOPE

HYDROGEN OFFSHORE PRODUCTION FOR EUROPE

Project ID	101111899
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	HORIZON-JTI-CLEANH2-2022-01-10: Demonstrating offshore production of renewable hydrogen
Project total costs	EUR 40 287 430.00
Clean H_2 JU max. contribution	EUR 20 000 000.00
Project period	1.6.2023–31.5.2028
Coordinator	Lhyfe, France
Beneficiaries	Alfa Laval Copenhagen A/S, Centre for New Energy Technologies SA, Commissariat à l'énergie atomique et aux énergies alternatives, DWR eco GmbH, ERM France, Frames Energy Systems BV, Provinciale Ontwikkelingsmaatschappij West-Vlaanderen, Strohm BV

https://hope-h2.eu/

PROJECT AND GENERAL OBJECTIVES

The project aims to pave the way for the deployment of the 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.

This unprecedentedly large-scale project (10 MW) will be able to produce up to 4 t/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.

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: production and compression (at medium pressure) at sea; export by composite pipeline; and then compression (at high pressure), storage and distribution onshore.

NON-QUANTITATIVE OBJECTIVES

The project 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, and also research, development and innovation work focusing mainly on optimising technological solutions and the operation of this type of infrastructure.

PROGRESS AND MAIN ACHIEVEMENTS

- **A recycled offshore barge.** The structure housing the production unit will be a second-hand jackup 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.
- **A 10 MW polymer electrolyte membrane electrolyser.** The first of its size to be installed offshore.
- **A 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 using a flexible thermoplastic composite pipeline over 1 km long, which will transport hydrogen produced at sea for the first time after being given the technical certification for this specific use.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?	SOA result achieved to date (by others)	Year for reported SOA result
SRIA (2021–2027)	Degradation	%/1 000 h	0.15		0.19	2020
	Cold start ramp time	seconds	10		30	
	Hot idle ramp time	seconds	1		2	
	Electricity consumption @ nominal capacity	kWh/kg	52		55	

HYDROSOL-BEYOND

THERMOCHEMICAL HYDROGEN PRODUCTION IN A SOLAR STRUCTURED REACTOR: FACING THE CHALLENGES AND BEYOND

Project ID	826379
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	FCH-02-4-2018: Thermochemical hydrogen production from concentrated sunlight
Project total costs	EUR 2 999 940.00
Clean H_2 JU max. contribution	EUR 2 999 940.00
Project period	1.1.2019–31.03.2024"
Coordinator	Ethniko Kentro Erevnas Kai Technologikis Anaptyxis, Greece
Beneficiaries	Abengoa Innovacion Sociedad Anónima, Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, Commissariat à l'énergie atomique et aux énergies alternatives, Deutsches Zentrum für Luft- und Raumfahrt EV, EngiCer SA, HyGear BV, HyGear Fuel Cell Systems BV, HyGear Hydrogen Plant BV, HyGear Operations BV, HyGear Technology and Services BV, Scuola universitaria professionale della Svizzera italiana

http://www.hydrosol-beyond.certh.gr/

PROJECT AND GENERAL OBJECTIVES

The Hydrosol-beyond project is a continuation of the Hydrosol-technology series of projects, which focus on using concentrated solar power to produce hydrogen from the dissociation of water through redox-pair-based thermochemical cycles. Hydrosol-beyond is an ambitious scientific endeavour aiming to address the major challenges and bottlenecks identified during previous projects and to further boost the performance of solar hydrogen production technology through innovative solutions that will increase the potential of the technology's future commercialisation.

NON-QUANTITATIVE OBJECTIVES

- Heat recovery.
- Minimisation of the parasitic losses mostly related to the high consumption of inert gas.
- Improvement of reactor design.

PROGRESS AND MAIN ACHIEVEMENTS

- Stable $NiFe_2O_4$ lattice structures have been produced.
- The durability of the $NiFe_2O_4$ lattice structures has reached 430 cycles, but not end of life. The material is still operating at a stable performance.
- A small-scale hybrid ceramic/metallic heat exchanger has been constructed and tested. The results were taken into account in the development of the full-scale heat exchanger.
- The production of $NiFe_2O_4$ lattice structures for application on the tubular solar reactor at the solar platform has been scaled up.
- A scaled-up hybrid ceramic/metallic heat exchanger has been constructed and integrated into the solar platform.
- The indirectly irradiated tubular solar reactor was operated under suboptimal conditions. The hydrogen production was at the same level as in the directly irradiated solar cavity reactor.

FUTURE STEPS AND PLANS

Operation of the Hydrosol solar platform with integrated heat recovery system will take place.

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
AWP 2018	Demonstrate the process at a realistic scale and under realistic working conditions, using existing solar demonstration facility (> 200 kW range)	kW/reactor	250	150	✓	250	2018
	Durability	cycles	1 000	430		602	2018
	Achieve heat recovery rates of high-temperature heat in excess of 60 %	%	60	46	⚙	N/A	2018
	Water-splitting redox material durability	cycles	1 000	400		600	N/A
	Solar-to-fuel efficiency	%	> 5 % in field tests	6.60		5	2017

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HYIELD

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

hyield

Project ID	101137792
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	HORIZON-JTI-CLEANH2-2023-01-05: Waste to hydrogen demonstration plant
Project total costs	EUR 15 512 377.50
Clean H_2 JU max. contribution	EUR 9 999 964.63
Project period	1.1.2024–31.12.2027
Coordinator	Magtel Operaciones SL, Spain
Beneficiaries	Agencia Estatal Consejo Superior de Investigaciones Científicas, Aquambiente Circular Economy Solutions SL, ArcelorMittal Bremen GmbH, AristEng SARL, Cartago Ventures SL, Cemex España Operaciones SL, Cetaqua, Centro Tecnológico del Agua, Fundación Privada, Enagás SA, Fundació Eurecat, Hydrogen Onsite SL, La Farga Lacambra SA, Mincatec Energy SAS, SINTEF AS, Synhelion SA, Waste to Energy Advanced Solutions SL

https://hyield.eu/

PROJECT AND GENERAL OBJECTIVES

The overall objective 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.

The project aims to build Europe's first large-scale waste-to-hydrogen demonstration plant, which will produce over 400 t 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 the production of a volume 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 the H2site membrane separation reactor and it will be implemented at a Cemex cement factory in Spain, where the green hydrogen produced will be utilised in cement production.

NON-QUANTITATIVE OBJECTIVES

- Design a multistage 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 the H_2 yield.
- Develop new digital tools and models for optimising the performance of waste-to-hydrogen plants.
- Unlock the energy potential in new organic waste feedstock for 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 an industrial scale.
- Develop and test a novel metal hydride hydrogen storage unit at an industrial scale.
- Validate the integrated waste-to-hydrogen plant at the near-industrial scale and in a real-world setting.
- Validate the 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.

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 for June 2024 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	LCOH at target production	€/kg	2.19		2.8-3 USD/kg	N/A
	Conversion efficiency	%	> 65		2020	N/A
SRIA (2021–2027)	System operational cost	€/kg	0.00512		13	2020
	System capital cost	€/(kg/day)	1.2		1.806	2020
	System carbon yield	kg H_2/kg C	0.32		0.15	2020

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HYP3D

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

Project ID	101101274
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	HORIZON-JTI-CLEANH2-2022-01-01: Development and validation of pressurised high temperature steam electrolysis stacks (solid oxide electrolysis)
Project total costs	EUR 2 543 398.75
Clean H_2 JU max. contribution	EUR 2 543 398.75
Project period	1.1.2023–31.12.2025
Coordinator	Fundació Institut de Recerca de l'Energia de Catalunya, Spain
Beneficiaries	3DCeram Sinto SAS, Centro Nacional de Supercomputación, Danmarks Tekniske Universitet, H2B2 Electrolysis Technologies SL, Politecnico di Torino, Snam SpA, Vac Tron SA

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 P2G and hydrogen refuelling station applications. HYP3D manufacturing technology represents a breakthrough compared with traditional ceramic SOEC processing due to a significant reduction in the time to market (from years to months), the use of raw materials (76 % reduction)and the required initial investment (42 % reduction from conventional cell manufacturing plants, from the first MW) while introducing great flexibility and scalability to the production lines.

NON-QUANTITATIVE OBJECTIVES

- Develop disruptive electrolyte-supported SOECs 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 through surface modification.
- Fabricate ultra-compact and lightweight kW-range stacks.
- 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 stand-alone HYP3D stacks for the particular applications of H_2 injection in the gas grid and on-site generation for hydrogen refuelling stations.

PROGRESS AND MAIN ACHIEVEMENTS

- The large-area cell 3D-printing processes were successfully optimised. 3YSZ 3D-printed cells were produced with good reproducibility and were successfully tested at atmospheric pressure, with performance in line with the literature.
- 8YSZ 3D-printing pastes were successfully developed and the printing process optimised.
- Commercial glass–ceramic sealants were successfully modified to increase their viscosity at operating temperatures with a refractory behaviour and possibly withstand the differential pressure and the shear stresses generated during operations in real conditions.
- A process for laser milling of metallic interconnects was developed to increase the surface roughness of the metals in the sealing regions, thus increasing the interlocking effect and the resistance to shear stresses.
- Protective coating deposition by electrophoretic deposition was developed and the sintering treatment optimised.
- First simplified thermomechanical and fluid dynamics simulations were successfully performed.

FUTURE STEPS AND PLANS

- Print and test 3YSZ large-area cells with high-pressure features.
- Develop high-pressure test stations and protocol without the use of pressure vessels.
- Optimise the debinding and sintering treatment for 8YSZ large-area cells.
- Validate the pressure resistance of the developed sealing approaches.
- Increase the level of complexity of the simulations.
- Build and test 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	
	Power per stack	kW	2.14	0.85 kW (by three-cell substack)	
	Injected current density	A/cm²	– 0.9 at 1.3 V	– 0.4 at 1.3 V	

HYPRAEL

ADVANCED ALKALINE ELECTROLYSIS TECHNOLOGY FOR PRESSURISED H2 PRODUCTION WITH POTENTIAL FOR NEAR-ZERO ENERGY LOSS

Project ID	101101452
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	HORIZON-JTI-CLEANH2-2022-01-03: Development of low temperature water electrolysers for highly pressurised hydrogen production
Project total costs	EUR 3 134 235.00
Clean H_2 JU max. contribution	EUR 2 653 915.00
Project period	1.3.2023–28.2.2026
Coordinator	Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón, Spain
Beneficiaries	Agfa-Gevaert NV, Fraunhofer Gesellschaft zur Förderung der angewandten Forschung EV, Green Hydrogen Systems A/S, Rhodia Laboratoire du Futur, Rhodia Operations, Solvay Specialty Polymers Italy SpA, Veco BV

http://hyprael.eu/

PROJECT AND GENERAL OBJECTIVES

Hyprael's goal is to develop and validate the next generation of alkaline electrolysis for highly pressurised H_2 production (at least 80 bar and preferably 100 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 the design and advanced assessment of electrocatalysts and polymers to the engineering and process intensification of an innovative cell design in four phases: (i) material development for pressurised electrolysis with an elevated temperature, (ii) screening of materials for applicability in pressurised electrolysers (both phases 1 and 2 will be performed at the lab scale / on a single cell with an area of 10 cm^2, 1–30 bar, 80–120 °C), (iii) scale-up of the most promising materials from phases 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 (Elyntegration) project at 60 bar, 120 °C and 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 developed by Green Hydrogen Systems in a new test bench. In addition, the Hyprael concept will strongly focus on developing an energy-efficient high-pressure electrolyser while addressing the circularity principle of the objectives of the EU for a carbon-neutral economy.

PROGRESS AND MAIN ACHIEVEMENTS

In this stage of the project, the focus is to cover the development of electrodes, separators and stacks. The first year of the project is focused on the development of substrate materials (aiming to identify and produce the best structures), the selection of catalysts capable of withstanding the demanding operating conditions, and the assessment and optimisation of the coating procedures and tools. It is making progress in identifying specialty polymers and materials to act as binders and functional additives for separator design. It has produced a report on selected functional materials and combination strategies for separator preparation. The project is in the process of finalising the design of the novel pressurised stack, and assembly is under way for the stack to be tested at the pilot scale with state-of-the-art components. The activities will continue in the coming months, so conclusive results are still pending.

FUTURE STEPS AND PLANS

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

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
SRIA (2021–2027)	CAPEX	€/kW	450	
	O&M cost	€/(kg/day)/year	40	
	Cold idle ramp time	seconds	600	
	Electricity consumption @ nominal capacity	kWh/kg	48	
	Current density	A/cm^2	1	
	Hot idle ramp time	seconds	10	
	Use of critical raw materials as catalysts	mg/W	0	
	Output pressure	bar	80	
	Degradation	%/1 000 h	0.1	
Project's own objectives	Temperature	°C	120	
	LCOH	€/kg	≤ 3	

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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 2024	Pillar 1 – Renewable hydrogen production
Call topic	HORIZON-JTI-CLEANH2-2022-01-05: Scaling up of cells and stacks for large electrolysers
Project total costs	EUR 5 295 799.25
Clean H_2 JU max. contribution	EUR 5 295 799.25
Project period	1.6.2023–31.5.2027
Coordinator	Cutting-Edge Nanomaterials UG Haftungsbeschränkt, Germany
Beneficiaries	Bekaert NV, Commissariat à l'énergie atomique et aux énergies alternatives, Consiglio Nazionale delle Ricerche, Deutsches Zentrum für Luft- und Raumfahrt EV, Dimosia Epicheirisi Ilektrismou Anonymi Etaireia, HyGear BV, HyGear Fuel Cell Systems BV, HyGear Hydrogen Plant BV, HyGear Operations BV, HyGear Technology and Services BV, META Group SRL, Univerza v Ljubljani

www.hyscale.eu

PROJECT AND GENERAL OBJECTIVES

The Hyscale project 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 (SOA) electrolysers. The technology is free of critical raw materials, fluorinated membranes and ionomers, meeting a significant fraction of the 2024 key performance indicators at the lab scale. Unique materials and design allow for cost-effective upscaling. The project 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 EUR 400 kW, validated at technology readiness level 5 in an industrially relevant environment, accelerating technology development and promoting sustainability in Europe.

PROGRESS AND MAIN ACHIEVEMENTS

- Membrane and electrode tasks have been initiated; initial testing and distribution of samples are complete.
- A cluster meeting was held to select porous transport layer structures.
- A uniform testing protocol was established for cell testing across partners.
- Gas permeability measurement methods are being evaluated.
- PTL compatibility with electrodes is being assessed.
- Stack design has commenced, with modifications made for simplicity and cost-effectiveness.

FUTURE STEPS AND PLANS

The AionFLX™ membrane will be optimised towards gas permeation and its synthesis will be upscaled for membrane production larger than 600 cm^2. The electrode-upscaling task will be close to finalised by the end of the year. The PTL production-upscaling task to 400 cm^2 will be halfway to completion by the end of 2024; we expect results in this field.

The Hyscale materials have already been assessed in the final size of 400 cm^2 in a single cell; the next step is to prove their high levels of performance and stability. The short-stack and prototype designs will take a big step forward in 2024.

Two milestones should be reached in 2024:

- achievement of high-performance and durable Hyscale cells,
- assessment of large-area cells.

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	N/A		65.5	2021
	System size	kW	100	N/A		2.4	2021
	Stack performance	A/cm @ 2 V/cell	2	N/A		0.47	2020
Project's own objectives and SRIA (2021–2027)	Degradation	%/1 000 h	0.9	N/A		1	2021
	Use of CRM as catalysts	mg/W	0	0 125		1.7	2021
	System capital cost	€/kW	400	N/A		3 750	2021
	Electricity consumption @ nominal capacity	kW/kg	50	N/A		53.3	2021
SRIA (2021–2027)	Current density	A/cm^2	2	N/A		0.5	2020

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HYSELECT

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

Project ID	101101498
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	HORIZON-JTI-CLEANH2-2022-01-06: Efficiency boost of solar thermochemical water splitting
Project total costs	EUR 3 982 105.00
Clean H_2 JU max. contribution	EUR 3 982 104.50
Project period	1.1.2023–31.12.2026
Coordinator	Deutsches Zentrum für Luft- und Raumfahrt EV, Germany
Beneficiaries	Aalto-korkeakoulusäätiö SR, Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile, Ethniko Kentro Erevnas Kai Technologikis Anaptyxis, FEN Research GmbH, Grillo-Werke AG, HelioHeat GmbH

https://www.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 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 complete overall HYS 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 thermochemical hydrogen production.

Hyselect will demonstrate the production of H_2 by splitting water using concentrated solar technologies, with an attractive efficiency and cost, through the hybrid sulphur cycle. Hyselect will introduce, develop and operate under real conditions a complete H_2 production chain focusing on the SAD-STS reactor and the SDE. In the course of the work, non-critical materials and catalysts will be developed, qualified and integrated into the plant-scale prototype units for both the SAD-STS reactor and the SDE unit. Experimental work will be accompanied by component modelling and overall process simulation and culminate with a demonstration of the complete process, integrating its key units (a solar particle receiver, a hot particle storage system, a splitting reactor and an electrolyser) into a pilot plant. Testing for a period of at least 6 months in a large-scale solar tower, driven by smart operation and control strategies, will establish Hyselect's target efficiency and costs. Finally, an overall process evaluation will be carried out to assess the technical and economic prospects of the Hyselect technology, which are directly linked to the know-how and developments in the sulphuric acid and water electrolyser industries.

NON-QUANTITATIVE OBJECTIVES

- Successful pilot-scale HYS technology demonstration.
- Implementation of sulphuric acid decomposition and SDE devices under industry-compatible and -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 AND MAIN ACHIEVEMENTS

The first flow chart of the Hyselect demo plant was drafted, including simulations for the mass and energy balances of the key blocks. This flow chart and the calculations serve as the basis for the design and dimensioning of the key blocks.

FUTURE STEPS AND PLANS

All key technology blocks will be designed, dimensioned and constructed. These blocks will be integrated into the demo plant to demonstrate the experimental operation of the Hyselect process.

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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 of < 10 % for at least 3 000 hours on stream exposure equivalent through accelerated tests	
	Development, construction and qualification of optimised SDE stack demonstrating stack cost reduction potential of two to three times that of known analogues without use of platinum group metals	hours	Operation of at least 100 hours	
	Scaled-up process plant layouts and techno-economic analysis demonstrating an optimised scenario	€/kg	Hydrogen production cost < 5€/kg	
	Demonstration of on-sun and off-sun solar tower testing campaigns with particle receiver prototype	°C	Temperature drop in hot storage tank less than 100 °C for 16 hours	
	Open access publications in scientific journals	number	> 20	
	Efficient prototype heat exchanger for gas streams SO_2, SO_3, O_2, H_2O	number	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 and direct normal irradiance	
	Demonstration of on-sun and off-sun solar tower testing campaigns with particle receiver prototype	°C	Delivery of particles with temperatures of 900–1 000 °C	
	Gas separation system providing clean SO_2 to the SDE	number	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 (five-cell) design incorporating Au catalytic materials to eliminate or minimise SO_2 carry-over from anode to cathode	hours	Demonstration of operation for < 50 hours	
	Presentations at international conferences	number	> 20	
	Upgrade and improved design of the existing particle-heated, high-efficiency, lab-scale prototype sulphuric-acid-splitting reactor	hours	Test operation for at least 100 hours	
	A particle-heated prototype reactor for sulphuric acid splitting	number	Design and construction	
SRIA (2021–2027)	Scaled-up process plant layouts and techno-economic analysis demonstrating an optimised scenario	k €/kg/day	Reduction of CAPEX from 15.19 k€/kg/dayin 2024 (design year) to 7.41 k€/kg/day by 2030	
	Experimental demonstration of the 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 demonstrating an optimised scenario	€/kg	Reduction of OPEX from 0.59€/kg in 2024 (design year) to 0.30 €/kg by 2030	

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MULTIPLHY

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

Project ID	875123
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	FCH-02-2-2019: Multi megawatt high-temperature electrolyser for valorisation as energy vector in energy intensive industry
Project total costs	EUR 9 751 722.50
Clean H_2 JU max. contribution	EUR 6 993 725.39
Project period	1.1.2020–31.12.2024
Coordinator	Commissariat à l'énergie atomique et aux énergies alternatives, France
Beneficiaries	Engie, Engie Energie Services, Neste Engineering Solutions BV, Neste Engineering Solutions Oy, Neste Netherlands BV, Neste Oyj, Paul Wurth SA, Sunfire GmbH

https://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 MW and a hydrogen production rate of ≥ 670 Nm³/h. Multiplhy's electrical efficiency (85 %) will be at least 20 % higher than the 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, Netherlands, demonstrating both technological and industrial leadership of the EU in the application of SOEC technology. The central element of the project is the manufacturing and demonstration of a multi-MW HTE and its operation in a renewable product refinery. As a result, Multiplhy promotes the SOEC-based HTE from technology readiness level 7 to 8.

NON-QUANTITATIVE OBJECTIVES

The Multiplhy project aims to scale up technology to the multi-MW level by optimising efficiencies, increasing availability, improving operations and improving stack durability. The system was installed on-site in April 2023 and the target start-up date was August 2023. The designs of the HTE and hydrogen-processing unit focus on high efficiency, with the 12 modules passing the quality criterion of electrical consumption below 42 kWh/kg H_2. A service and maintenance concept has been defined, and real availability will be monitored during the operation phase.

The project has also reduced capital cost and operation and maintenance expenditure by developing a design-to-cost strategy and refining the cost analysis. Techno-economic evaluations have been performed, providing methodology and reference values for various scenarios, and determining the impact of electricity prices, efficiency and the capital expenditure total integration cost.

PROGRESS AND MAIN ACHIEVEMENTS

- The project demonstrated stack durability for more than 7 000 hours without H_2 production loss for small stacks.
- The testing of durability on large stacks (> 10 kW) is ongoing for two types of stack (electrolyte-supported cell and anode-supported cell) with no H_2 production loss.
- A new-generation HTE module was developed to decrease capital expenditure.
- Factory acceptance testing of all 12 modules was completed.
- The HTE and hydrogen-processing unit were installed on site.
- Cold commissioning was performed.

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	16 000		N/A	N/A
AWP 2019	Electrical consumption	kWh/kg	39.2		39.7	2017
	H_2 production loss at the stack level	%/1 000 h	1.2	✓	1.9	2017
	Downtime	%	2		N/A	N/A

NEWELY

NEXT GENERATION ALKALINE MEMBRANE WATER ELECTROLYSERS WITH IMPROVED COMPONENTS AND MATERIALS

Project ID	875118
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	FCH-02-4-2019: New anion exchange membrane electrolysers
Project total costs	EUR 2 597 413.75
Clean H_2 JU max. contribution	EUR 2 204 846.25
Project period	1.1.2020–29.6.2023
Coordinator	Deutsches Zentrum für Luft- und Raumfahrt EV, Germany
Beneficiaries	Air Liquide Forschung und Entwicklung GmbH, Commissariat à l'énergie atomique et aux énergies alternatives, Cutting-Edge Nanomaterials UG Haftungsbeschränkt, DLR-Institut für Vernetzte Energiesysteme EV, Fondazione Bruno Kessler, Korea Institute of Science and Technology, L'Air Liquide SA, Membrasenz SARL, ProPuls GmbH, Ústav Makromolekulární chemie AV ČR v.v.i., Vysoká škola chemicko-technologická v Praze, Westfälische Hochschule Gelsenkirchen, Bocholt, Recklinghausen

https://www.newely.eu

PROJECT AND GENERAL OBJECTIVES

This project aimed to redefine AEMWE surpassing the current state of alkaline water electrolysis and bringing it one step closer to proton-exchange membrane WE in terms of efficiency, but at a lower cost. The three main challenges of AEMWE – membrane, catalyst and stack – were addressed by three small and medium-sized enterprises and a large hydrogen company supported by seven renowned research and development centres.

NON-QUANTITATIVE OBJECTIVES

The techno-economic assessment and life-cycle assessment demonstrated a reduction in CAPEX and OPEX for AEMWE relative to proton-exchange membrane WE and alkaline WE. Life-cycle assessment identified electricity as having the highest environmental impact of all water electrolyser technologies. Of the stack materials, PEEK and steel are identified as drivers of global warming potential and damage to resources, and their use should be reduced as much as possible or they should be replaced by alternatives with lower impacts.

PROGRESS AND MAIN ACHIEVEMENTS

- The membrane electrode assembly with OXYGN-N anode, H2GEN-M cathode and commercial AEM / ionomer achieves 2 V at 2 A/cm^2 in 0.1 M KOH. No irreversible degradation was seen in a 400-hour test.
- An AEM with conductivity of 62 mS/cm and area-specific resistance of 0.065 ohm/cm^2 was achieved.
- The project created a new method for AEM membrane reinforcement with covalent bonds between the matrix and ionomer, with conductivity of 62 mS/cm.
- A novel and innovative high-pressure AEMWE stack technology was designed and assembled for 200 cm^2 cells. Tests of a five-cell stack achieved 1.244 kW at 100 A.

FUTURE STEPS AND PLANS

The project has finished.

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
	Maximum AEMWE stack size realised in the project						
Project's own objectives and MAWP addendum (2018–2020)	Stack power	kW	2	0.075	(in progress)	2.4	2021
	Cell area	cm^2	200	25		N/A	2021
	Pressure	bar (relative)	≤ 40	N/A		≤ 35	2021
	Energy consumption @ power	kWh/kg @ W/cm^2	53.6 @ 2	53.6 @ 3.6		53.6 @ 2.4	2021
	Corresponding to cell voltage @ current	Corresponding to V @ A/cm^2	Corresponding to 2 @ 1	Corresponding to 2 @ 1.8		Corresponding to 2 @ 1.2	2021
	Non-PGM catalysts						
Project's own objectives and MAWP addendum (2018–2020)	Added overpotentials (anode and cathode)	mV	415	232	✓	250	2020
	Current density	mA/cm^2	1	1	✓	1	2020
MAWP addendum (2018–2020)	Stable operation for 2 000 hours, cell voltage gap after 2 000 hours of operation	mV	50	No 2 000-hour test yet	(in progress)	N/A	2021
	Extrapolated to efficiency degradation @ rated power and considering 8 000 hours of operations per year	Extrapolated to %/year	Extrapolated to 7.2	No test yet	(in progress)	N/A	2021
	Chemically, thermally and mechanically stable AEM ionomer and membrane with conductivity	mS/cm	≥ 50	62	✓	80	2021
	Area-specific resistance	ohm/cm^2	≤ 0.07	0.065	✓	0.045	2021

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NEWSOC

NEXT GENERATION SOLID OXIDE FUEL CELL AND ELECTROLYSIS TECHNOLOGY

Project ID	874577
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	FCH-02-6-2019: New materials, architectures and manufacturing processes for solid oxide cells
Project total costs	EUR 4 999 726.25
Clean H_2 JU max. contribution	EUR 4 999 726.25
Project period	1.1.2020–30.6.2023
Coordinator	Danmarks Tekniske Universitet, Denmark
Beneficiaries	Aktsiaselts Elcogen, Ceres Power Limited, Commissariat à l'énergie atomique et aux énergies alternatives, École polytechnique fédérale de Lausanne, Ethniko Kentro Erevnas Kai Technologikis Anaptyxis, Fundació Institut de Recerca de l'Energia de Catalunya, Hexis AG, Idryma Technologias Kai Erevnas, Instytut Energetyki, Nederlandse Organisatie voor toegepast natuurwetenschappelijk onderzoek, Politecnico di Torino, SolydEra SpA, Sunfire GmbH, Teknologian tutkimuskeskus VTT Oy, Università degli Studi di Salerno

http://www.newsoc.eu/

PROJECT AND GENERAL OBJECTIVES

Newsoc aimed to significantly improve the performance, durability and cost competitiveness of solid oxide cells and stacks compared with the state of the art, focusing on (i) structural optimisation and innovative architectures, (ii) alternative materials and (iii) innovative manufacturing. Newsoc succeeded in improving the cells, yielding a 25 % increase in applicable current density and a 25 % lower area-specific resistance, which marked the first milestone. Progress was achieved for all proposed concepts, and specific plans were agreed with the industry partners for integration into their commercial platforms.

NON-QUANTITATIVE OBJECTIVES

The Newsoc project provided a path on how to increase the technology readiness level, beyond the project period, towards level 6. Furthermore, the Newsoc project evaluated the new solid oxide cell materials and fabrication processes through a life-cycle impact assessment and cost assessment, including interpretation through the eco-efficiency framework.

A life-cycle assessment was carried out for six selected Newsoc concepts.

PROGRESS AND MAIN ACHIEVEMENTS

Newsoc succeeded in improving state-of-the-art (SOA) solid oxide cells and stacks and in developing promising concepts for further improvement beyond the project.

- **SOA materials improved.** These include the Ni/YSZ fuel electrode, LSCF/CGO air electrode and CGO barrier layer. The microstructural optimisation of the electrodes and the development of thin-film barrier layer technology (atomic layer deposition and room temperature sputtering) led to the improvement of performance and durability.
- **Alternative electrode materials improved specific durability parameters.** The parameters were (i) sulphur tolerance through an Ni/CGO-infiltrated, titanate-based fuel electrode, (ii) carbon tolerance through a bimetallic/trimetallic (Fe, Mo, Au) modified Ni/CGO fuel electrode, (iii) redox tolerance through an La-doped, chromite-based fuel electrode and (iv) reversible operation through (a) a Ni/CGO-infiltrated, titanate-based (La, Sr, Fe, Ni) fuel electrode and (b) a bimetallic/trimetallic (Fe, Mo, Au) modified Ni/CGO fuel electrode.
- **Reduction of toxic material use in the cells/stacks and during manufacturing.** This involved creation of a Co-free, LSF-based air electrode, the partial substitution of Co in Mn-Co-Cu-O spinel interconnect coatings and sealant deposition without toxic solvents.

All improved Newsoc concepts employ a scalable/well-established methodology, which eases adoption by industry. The Newsoc concepts can be exploited individually or in combinations (e.g. combining thinner barrier layers with improved electrodes). The results were validated in industrial cell and stack platforms in the Newsoc project, enabling fast uptake into industrial processes.

FUTURE STEPS AND PLANS

The project has finished.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SOA result achieved to date (by others)
Project's own objectives	Electrolysis current for operation with a degradation rate below 1 %/1 000 h	A/cm^2	1	0.75–1	✓	0.75
	Area-specific resistance	ohm cm^2	0.4	0.39		0.52
	Degradation rate under reversible operation	%/1 000 h	13	10		17
	Cost per cell	€/kW	5–10	5–10		N/A

NOAH2

NOVEL SOE ARCHITECTURES FOR HYDROGEN PRODUCTION

Project ID	101137600
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	HORIZON-JTI-CLEANH2-2023-01-02: Innovative solid oxide electrolysis cells for intermediate temperature hydrogen production
Project total costs	EUR 2 656 024.00
Clean H_2 JU max. contribution	EUR 2 655 084.00
Project period	1.12.2023–30.11.2026
Coordinator	Danmarks Tekniske Universitet, Denmark
Beneficiaries	Commissariat à l'énergie atomique et aux énergies alternatives, Genvia, Haute école spécialisée de Suisse occidentale, Idryma Technologias Kai Erevnas, Liberty Powder Metals, SINTEF AS

https://cordis.europa.eu/project/id/101137600

PROJECT AND GENERAL OBJECTIVES

The overall goal of the NOAH2 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. NOAH2 will boost the electrolysis performance of solid oxide cells and stacks significantly beyond the state of the art (SOA) through a combination of optimised structures and highly active materials, with a focus on reducing use of critical raw materials (CRMs) and improving manufacturability using well-established, large-scale routes for solid oxide technology. The NOAH2 stack architecture relies on a metal-based, monolithic concept with infiltrated electrodes.

NOAH2 will outline a path towards commercialisation, provide a sustainability classification with emphasis on substituting CRMs, provide an assessment of commercialisation potential compared with those of SOA SOEL, polymer electrolyte membranes and alkaline electrolysers, and identify potential industrial players for high-volume manufacture.

Specific technical objectives for NOAH2 are to:

- reduce the cost of SOEL stacks by 50 % compared with that of the SOA 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 by at least 20 % by developing a metal-based, monolithic structure;
- increase the hydrogen production rate (current density) by 20 % compared with that of the SOA, reaching 1.2 A/cm^2, through using innovative electrode materials and structuring with infiltration of materials of superior electrocatalytic activity at temperatures below 700 °C;
- demonstrate commercially viable durability with degradation rates below ~ 0.75 %/1 000 h at the stack level;
- reach SOEL operation in less than 6 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

NOAH2 will:

- outline a path towards commercialisation in terms of projecting costs for large-scale manufacture towards the MW and GW scales, reaching the 2030 targets of capital expenditure of ~ EUR 520/(kg/day) and operational expenditure of ~ EUR 45/(kg/day)/year;
- provide a sustainability classification (life-cycle analysis) with an emphasis on replacing CRMs;
- provide an assessment of commercialisation potential compared with those of SOA SOEL, polymer electrolyte membranes and alkaline electrolysers;
- identify and engage with potential industrial players for high-volume manufacture and further uptake of the project results.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?	SOA result achieved to date (by others)
Project's own objectives	Cell current density	A/cm^2	1.2		1
	Hot idle ramp time	seconds	240		N/A
	Degradation rate	%/1 000 h	0.75		N/A
	Cold start ramp time	hours	6		N/A

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OUTFOX

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

Project ID	101101439
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	HORIZON-JTI-CLEANH2-2022-01-09: Scaling-up technologies for SOEL
Project total costs	EUR 2 925 824.50
Clean H_2 JU max. contribution	EUR 2 925 824.00
Project period	1.2.2023–31.1.2027
Coordinator	Nederlandse Organisatie voor toegepast natuurwetenschappelijk onderzoek, Netherlands
Beneficiaries	Aktsiaselts Elcogen, Convion Oy, Elcogen Oy, Fondazione Politecnico di Milano, Linq Consulting & Management Ltd, Politecnico di Milano, Shell Global Solutions International BV, Teknologian tutkimuskeskus VTT Oy

http://outfoxproject.com

PROJECT AND GENERAL OBJECTIVES

The main objective of the Outfox project is to remove scale as a limiting factor in the deployment of SOEL technologies, while proving their potential to become the preferred option for green hydrogen production. By combining experimental results at 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 EUR 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 to the forefront of the green hydrogen technological landscape.

PROGRESS AND MAIN ACHIEVEMENTS

Reference scale cells with 400 and 300-micron half-cell thicknesses were manufactured to be implemented in short-stack and 80 kW stack manufacturing. Using the manufactured reference cells, reference-scale stacks for electrochemical testing have been manufactured. Upon successful implementation of the aforementioned activities, the first milestone of the project was reached. The reference-scale short stacks are being tested electrochemically. The successful completion of the testing activity of the reference-scale short stacks will result in the completion of the second milestone of the project. In addition, the following activities are in progress: (i) manufacturing and performance evaluation of industrial scaled-up cells (300 cm^2) and next-generation cells (900 cm^2) with reduced thicknesses, (ii) conceptual design of an upscaled solid oxide electrolysis module aiming to achieve even flow distribution using a 3D model (the initial simulation results are physically and numerically reasonable) and (iii) design of a modified 80 kW module with simplified and streamlined assembly. In addition, the design phase of a plant model for techno-economic and scale-up analysis has been finalised. The initial results are planned to be disseminated at the World Hydrogen Energy Conference and European Fuel Cell Forum during 2024.

FUTURE STEPS AND PLANS

Future steps include (i) validating high-surface-area cells (300 cm^2 and 900 cm^2) as single repeating units, (ii) determining an optimal cell size for near-future large-scale SOEL, (iii) optimising the industrial manufacturing process for scaled-up cells, (iv) modelling a novel stack architecture for scaled-up cells and (v) installing and validating an 80 kW system in a relevant industrial environment.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	LCOH	€/kg	2.7*	
	Cell area	cm^2	300–900	
	Module size	kW	400	
SRIA (2021–2027)	Current density	A/cm^2	0.85	
	Cold start ramp time	hours	12	
	Degradation @ UTN	%/1 000 h	< 1	
	O&M cost	€/(kg/day)/year	85	
	Hot idle ramp time	seconds	300	
	CAPEX	€/(kg/day), €/kW	600**, 400**	
	Electricity consumption @ nominal capacity Heat demand @ nominal capacity	kWh/kg	39 9	
	Footprint	m^2/MW	< 150	
	Current density	A/cm^2	0.85	

* Fixed OPEX is 2 €/kg, based on electricity price of 50 €/kg.
**This KPI value is based on system production volumes exceeding > 300 MW/year.

OYSTER

OFFSHORE HYDROGEN FROM SHORESIDE WIND TURBINE INTEGRATED ELECTROLYSER

Project ID	101007168
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	FCH-02-6-2020: Electrolyser module for offshore production of renewable hydrogen
Project total costs	EUR 5 423 843.01
Clean H_2 JU max. contribution	EUR 4 999 843.00
Project period	1.1.2021–31.12.2025
Coordinator	ERM France, France
Beneficiaries	Environmental Resources Management (previously Element Energy Limited), ITM Power (Trading) Limited, Orsted Hydrogen Netherlands Holding BV, Orsted Wind Power A/S, Siemens Gamesa Renewable Energy AS, Stiesdal Hydrogen A/S

https://oysterh2.eu/

PROJECT AND GENERAL OBJECTIVES

The overall aim of the Oyster project is to justify, develop and demonstrate an electrolyser suitable for deployment in offshore environments. The end goal is to produce a marinised electrolyser that is integrated with offshore wind turbines to produce 100 % renewable, low-cost bulk hydrogen, while facilitating increased roll-out of offshore wind.

NON-QUANTITATIVE OBJECTIVES

- The project aims to develop an electrolyser system capable of operating reliably in an offshore environment.
- It aims to deploy and test a new MW-scale electrolyser designed for marine environments for 18 months, covering all seasons.
- It aims to complete a design exercise for an integrated offshore wind turbine electrolysis module, drawing on the lessons from the pilot trial and insights from expert partners in the offshore oil and gas sector. These lessons and insights will contribute to the basis of a detailed design of a complete offshore hydrogen production system.
- The project plans to undertake a preliminary front-end engineering and design study for a specific offshore wind farm site, linked to an existing industrial hydrogen customer.
- It aims to formulate business cases for further deployment of large-scale electrolysis systems in offshore environments. A business case will be developed for the use of hydrogen across different applications, including hydrogen for industrial users, transport applications and heating, by exploiting the onshore gas networks for use in hydrogen distribution.

PROGRESS AND MAIN ACHIEVEMENTS

- The first versions of the water treatment system design and system modelling to be used for simulation of direct connected power electronics have been finalised.
- The water treatment system design has been completed for use in the marinised electrolyser system.
- The system design has commenced and long lead items have been ordered.

FUTURE STEPS AND PLANS

Discussions are under way for a potential partnership with a hydrogen valley funded by the Clean Hydrogen Joint Undertaking.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Time for hot start (minimum to maximum power)	seconds	-	
	Operational load	hours	3 000	
	Electrolyser footprint	m²/MW	50	
	Maintenance cost	€/(kg year)	20	
	Efficiency degradation at rated power	%/1 000 h	0.11	
	Current density	A/cm²	0.2–0.4	⚙
	Electrolyser CAPEX (at rated power) including ancillary equipment and commissioning	€/(kg/day)	800	
	Energy consumption at rated power (system AC efficiency, including BoP)	kWh/kg	51.6	
	Operational load run hours within the project	hours	3 000	
	Design of an integrated electrolyser–wind-turbine solution	%	Demonstrate a 30 % capital cost saving in electrolyser costs (avoided power electronics)	

PEACE

PRESSURIZED EFFICIENT ALKALINE ELECTROLYSER

Project ID	101101343
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	HORIZON-JTI-CLEANH2-2022-01-03: Development of low temperature water electrolysers for highly pressurised hydrogen production
Project total costs	EUR 2 504 965.00
Clean H_2 JU max. contribution	EUR 2 504 964.75
Project period	1.6.2023–31.5.2026
Coordinator	Deutsches Zentrum für Luft- und Raumfahrt EV, Germany
Beneficiaries	Brandenburgische Technische Universität Cottbus-Senftenberg, Danmarks Tekniske Universitet, GRANT Garant s.r.o, Hydrogen Chemical Company BV, Materials Mates Italia SRL, Technische Universiteit Eindhoven

http://www.h2peace.eu/

PROJECT AND GENERAL OBJECTIVES

The PEACE research and innovation project kicked off in June 2023. A collaboration of seven European research organisations and universities, with large and small companies on board, under the coordination of Deutsches Zentrum für Luft- und Raumfahrt, aims to develop a high-pressure alkaline electrolysis (AEL) technology to substantially reduce hydrogen production costs, thus 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 that is capable of operating at pressure exceeding 50 bar. The integration of advanced components, an 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 already be compressed, representing a significant advantage for its subsequent use in downstream processes operating with compressed hydrogen – reducing by a considerable percentage the capital expenditure and operational expenditure on the 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 impact. Its adverse environmental impact is presumed to be low.

NON-QUANTITATIVE OBJECTIVES

The main goal of PEACE is to reduce the levelised cost of hydrogen for green H_2 production. To achieve that, the project aims to achieve:

- 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-plant and auxiliary optimisation and qualification with a focus on high-pressure operation;
- technology demonstration by constructing and operating a newly developed, pressurised and high-efficiency stack of > 50 kW;
- 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 balance of plant.

PROGRESS AND MAIN ACHIEVEMENTS

- The qualification of non-precious components has started.
- The simulation scenarios have been established for the upstream and downstream integration and operation optimisation, considering a combination of the solar and wind power supplied, and also two possible downstream processes: ammonia production or methanol production.
- A solid data management plan based on the findability, accessibility, interoperability and reusability data policy has been implemented.
- A project communication strategy targeting multiple audiences is under way, focusing on the PEACE website and the PEACE LinkedIn and X profiles.

FUTURE STEPS AND PLANS

- Qualification of various cell and stack components will take place.
- The PEACE AEL stack demonstrator with the best-performing components will be assembled.
- Demonstrator enrichment with the dual-stage pressurisation concept will take place.
- When the demonstrator is in operation, PEACE will undertake evaluation of function, performance and characteristics simulations.
- Assessment of the environmental and other impacts of the PEACE technology will take place.

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- The PEACE AEL will be integrated with a chemical plant directly utilising the PEACE-produced hydrogen.
- The sustainability and circularity aspects of the project will be analysed in more detail. The data for the modelling will be based on communications with work programme 2, while the modelling carried out in work programme 4 will be used to understand the interaction between the AEL technology and the surrounding system (e.g. electricity, heat, and fuel requirements and production).

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	Maximum current density	A/cm^2	1.45		0.6	2020
	Pressurisation energy consumption	kWh/kg H_2	0.46		0.5	N/A
	Overall system efficiency	%	68–72		66.7	2020
	Nominal current density	A/cm^2	1		N/A	N/A
	Minimal load	% of nominal load	14		N/A	N/A
	Voltage efficiency (LHV)	%	62–75		55–62	N/A
	Minimum pressurisation level	bar	50		N/A	N/A
	Cell voltage	V	1.65–2.00		1.9–2.3	N/A
	Use of critical materials	mg/W	0		0.6	2020
	Specific energy use	kWh/kg	49		50–59	N/A
	Minimum stack size	kW	50		N/A	N/A
	LCOH	€/kg	3		5	N/A
Project's own objectives and SRIA (2021–2027)	Degradation rate	%/kh	0.11		0.12	2020
	Electrical consumption @ nominal capacity	kWh/kg	48		50	2020

PH2OTOGEN

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

Project ID	101137889
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	HORIZON-JTI-CLEANH2-2023-01-04: Photoelectrochemical (PEC) and/or photocatalytic (PC) production of hydrogen
Project total costs	EUR 2 498 813.75
Clean H_2 JU max. contribution	EUR 2 498 813.25
Project period	1.1.2024–30.6.2027
Coordinator	Toyota Motor Europe NV, Belgium
Beneficiaries	Commissariat à l'énergie atomique et aux énergies alternatives, École polytechnique fédérale de Lausanne, Friedrich-Alexander-Universität Erlangen-Nürnberg, Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, LGI Sustainable Innovation, Solaronix SA, Stichting Nederlandse Wetenschappelijk Onderzoek Instituten

https://www.ph2otogen.eu/

PROJECT AND GENERAL OBJECTIVES

The Ph2otogen project 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, Ph2otogen aims to couple hydrogen generation with the oxidation of an organic molecule, such as glycerol oxidation to 1,3-dihydroxyacetone (DHA), in place of oxygen formation. There are several advantages to this approach: (i) it avoids the concomitant production of hydrogen and oxygen, which can result in the formation of an explosive mixture; (ii) since the products are in different states – hydrogen being a gas and DHA an oil – they can be easily separated without the need for specially engineered membranes; and (iii) DHA is around 50 times more valuable than the glycerol starting material and therefore provides another possible revenue stream from the device, which is likely to accelerate the introduction of green hydrogen to the market.

NON-QUANTITATIVE OBJECTIVES

- Development of novel semiconductor materials for hydrogen evolution and glycerol oxidation.
- Building and outdoor testing of a demonstrator capable of concomitant hydrogen evolution and glycerol oxidation.
- Life-cycle and techno-economic 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).

FUTURE STEPS AND PLANS

As a first step, the project is focusing on the synthesis of the hydrogen evolution particles and the oxidising particles and the testing of them at the laboratory scale.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Develop stable and efficient tandem system	Efficiency: % Size: cm^2	Average of > 5 % solar-to-hydrogen efficiency over 500 hours, with oxidation reaction forming a value added product (> 70 % purity) Size: 5–10 cm^2	
	Life-cycle assessment (LCA) and techno-economic analysis (TEA) studies to establish competitive advantage	-	LCA and TEA ready for use by partners	
	Develop stable and efficient oxidising particle	%	Activity for oxidation that matches 5 % solar-to-hydrogen efficiency under sacrificial conditions over 500 hours	
	Demonstration device with power density of 25 kWh/m^2	Power density: kWh/m^2 Performance: % Size: cm^2	Power density: 25 kWh/m^2 Performance: Average of > 5 % solar-to-hydrogen efficiency over 500 hours, with oxidation reaction forming a value added product (> 70 % purity) Size: 500 cm^2	
	Develop stable and efficient hydrogen-evolving particle	%	Average of > 5 % solar-to-hydrogen efficiency under sacrificial conditions over 500 hours	
	Modelling to define flow rates with quantitative agreement with results	-	Qualitative agreement of the model with experimental results	

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PILOTSOEL

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

Project ID	101112026
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	HORIZON-JTI-CLEANH2-2022-01-04: Design for advanced and scalable manufacturing of electrolysers
Project total costs	EUR 2 000 000.00
Clean H_2 JU max. contribution	EUR 2 000 000.00
Project period	1.6.2023–31.5.2026
Coordinator	Danmarks Tekniske Universitet, Denmark
Beneficiaries	Aktsiaselts Elcogen, Beneq Oy, Elcogen Oy, SIA Naco Technologies, Univerza v Ljubljani

https://pilotsoel.dtu.dk/

PROJECT AND GENERAL OBJECTIVES

The Pilotsoel project will focus on innovative upscalable and low-cost SOEL-component manufacturing processes, with reduced use of critical raw materials and increased waste recycling in the cell production processes, and will increase the degree of automation in the stack assembly to reduce manufacturing cost.

The project 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.

The project is aiming to improve the SOEL processing manufacturing readiness level (MRL) from MRL 4 at the beginning of the project to at least MRL 5 by the end of the project.

PROGRESS AND MAIN ACHIEVEMENTS

A review of the list of coating candidates for the air and fuel sides of interconnector plates has been undertaken.

The design of the optical inspection system for stack assembly automation and quality assurance has been finalised.

FUTURE STEPS AND PLANS

The project will continue working on optimising the manufacture routes for SOEL cells, characterising the manufactured cells and stacks, SOEL interconnector coating and stack assembly with improved optical inspection system.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
SRIA (2021–2027)	CAPEX	€/(kg/day)	1 800	
	Degradation @ UTN	%/1 000 h	< 1	
	O&M cost	€/(kg/day)/year	130	
	20 kW stack assembly	number	20 kW stack assembled and validated	
	Current density	A/cm²	0.85	
	SOEL cell degradation rate	%/1 000 h	< 1	
	Hot idle ramp time	seconds	180	
	Cold start ramp time	hours	4	
	Electricity consumption @ nominal capacity	kWh/kg	38	
	SOEL stack degradation	%/1 000 h	< 1	
Project's own objectives	Interconnector coating degradation	mohm/cm²	5 mohm/cm² after 3 000 hours	
	Waste material recycling	%	Up to 100 % recycling 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	

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PRESSHYOUS

PRESSURISED HYDROGEN PRODUCED BY HIGH TEMPERATURE STEAM ELECTROLYSIS

Project ID	101101337
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	HORIZON-JTI-CLEANH2-2022-01-01: Development and validation of pressurised high temperature steam electrolysis stacks (solid oxide electrolysis)
Project total costs	EUR 2 499 426.00
Clean H_2 JU max. contribution	EUR 2 499 426.00
Project period	1.9.2023–31.8.2026
Coordinator	Commissariat à l'énergie atomique et aux énergies alternatives, France
Beneficiaries	Aktsiaselts Elcogen, École polytechnique fédérale de Lausanne, Genvia, Haute école spécialisée de Suisse occidentale, HyGear BV, HyGear Fuel Cell Systems BV, HyGear Hydrogen Plant BV, HyGear Operations BV, HyGear Technology and Services BV, Nederlandse Organisatie voor toegepast natuurwetenschappelijk onderzoek, Teknologian tutkimuskeskus VTT Oy

https://cordis.europa.eu/project/id/101101337

PROJECT AND GENERAL OBJECTIVES

Presshyous aims to deliver scientific insights on SOEL H_2 production under pressure and to therefore foster rapid industrial empowerment. It will provide two major deliverables: a validated lab-scale 30-bar/20 kWe stack in a pressurised vessel and a 10-bar pressurised stack operated without needing a pressure vessel.

NON-QUANTITATIVE OBJECTIVES

PressHyous is a project that aims to optimize individual components in large-scale HP SOEL systems using modelling tools developed by partners. 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 H2 delivery conditions renders LCA results hardly comparable. A LCA of a pressurised H2 production process based on PressHyous concepts will help identify major environmental aspects and analyze the environmental benefits of energy system integration throughout the project's use cases.

PROGRESS AND MAIN ACHIEVEMENTS

The main achievements during months 1–6 were:

- the characterisation protocol of SOEL cells under pressurised conditions.
- the definition of use cases, in collaboration with the Advisory Board.
- the delivery of reference single cells and the start of the testing campaign.

FUTURE STEPS AND PLANS

- The project will improve the cell and other stack components (including interconnects, sealings, interconnect protective coatings and stack clamping system).
- Presshyous will design, assemble and validate 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).
- It will investigate a promising pressurised stack concept that does not need a pressure vessel, thus relieving the cost of the balance of plant. This will be tested up to 10 bar at the short-stack scale, with a similar current density to the stack operated in a pressurised vessel.
- Presshyous will supply model-based insights for H_2 production for up to five identified use cases, providing information on the expectable performances of both stack concepts (with or without a pressurised vessel) in large-scale developments. This work will be strongly linked to TEA and LCA.
- The project will complete TEA and LCA of the use cases, showing the applicability and the benefits of the developed technologies and the two stack concepts compared with alkaline electrolysis and proton-exchange membrane electrolysis when operating under pressure.

These steps 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.

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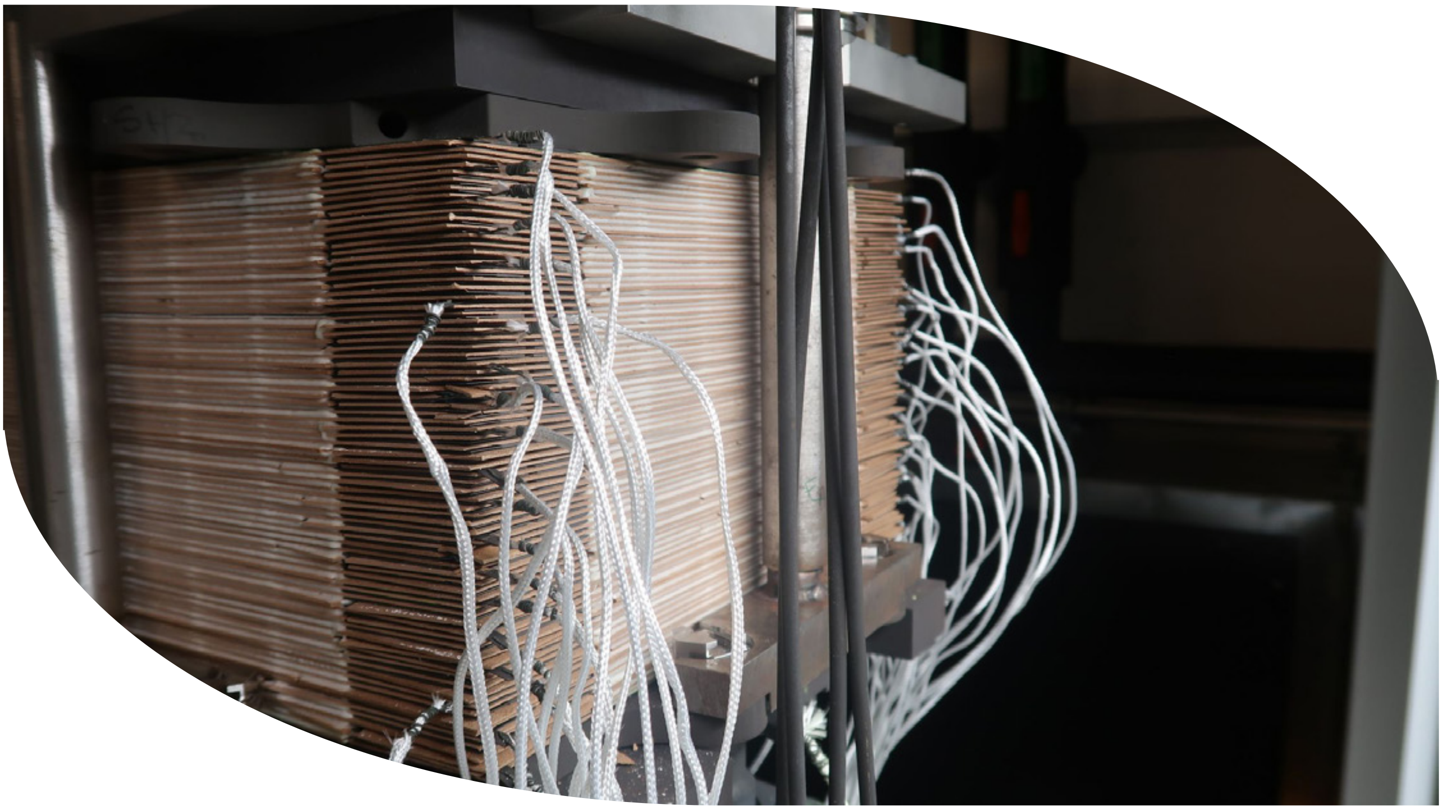
PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?	SOA result achieved to date (by others)
Project's own objectives	Heat demand @ nominal capacity	kWh/kg	9	⚙	9.9
	Hot idle ramp time	seconds	300		600
	Current density	A/cm²	1		0.6
	Degradation @ UTN	%/1 000 h	1		1.9
	O&M cost	€/(kg/day)	130		410
	Electricity consumption @ nominal capacity	kWh/kg	34–36		40
	Cold start ramp time (P-stack)	hours	8		12
	CAPEX	€/kW	1 250		2 130



PROTOSTACK

TUBULAR PROTON CONDUCTING CERAMIC STACKS FOR PRESSURIZED HYDROGEN PRODUCTION

Project ID	101101504
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	HORIZON-JTI-CLEANH2-2022-01-02: Development and validation of pressurised high temperature steam electrolysis stacks (proton conducting ceramic electrolysis)
Project total costs	EUR 2 497 013.75
Clean H_2 JU max. contribution	EUR 2 497 013.75
Project period	1.1.2023–31.12.2025
Coordinator	SINTEF AS, Norway
Beneficiaries	Agencia Estatal Consejo Superior de Investigaciones Científicas, Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile, Atena SCARL – Distretto Alta Tecnologia Energia Ambiente, CoorsTek Membrane Sciences AS, Demcon Energy Systems BV, Demcon High-Tech Systems Enschede BV, Demcon Life Sciences & Health Eindhoven BV, Shell Global Solutions International BV, Università degli Studi di Napoli Parthenope

https://protostack.eu/

PROJECT AND GENERAL OBJECTIVES

Protostack will create a radically new, compact and modular proton-conducting ceramic electrolyte 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 proton-conducting ceramic electrolyte technology from technology readiness level 2 to 4. To achieve its ambitious goals, the project consortium has gathered research and industry partners that are world-leading within proton ceramic technologies, with recognised expertise related to the research and development of electrolysers, membrane reactors, materials, electrochemistry and process engineering.

NON-QUANTITATIVE OBJECTIVES

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

PROGRESS AND MAIN ACHIEVEMENTS

The designs of the hot box and stack concept were finalised within the first year, and production of stack components is well under way.

The first year primarily focused on validation of key cell and stack components in terms of functionality, scalable manufacturing and stability and on the production of the first short stack with the new stack design for validation of the stack concept.

The project was also co-organiser of an autumn school in Valencia with more than 100 participants – mostly graduate students.

FUTURE STEPS AND PLANS

The second year will focus on continued validation and optimisation of cell and stack components, and dedicated programmes 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, along with an updated system balance of plant and safety assessment, will be a priority within the coming year.

Finally, detailed techno-economic and life-cycle analysis of the technology employed will be undertaken for specific integration scenarios and use cases.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SOA result achieved to date (by others)
Project's own objectives	Stack durability	%/khr	1.2	N/A		4
	Current density	A/cm²	0.5	0.3		N/A
	Stack production cost	€/kg/day	1 000	N/A		N/A
	Stack efficiency	% (HHV)	75	N/A		N/A

REACTT

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

Project ID	101007175
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	FCH-02-3-2020: Diagnostics and control of SOE
Project total costs	EUR 2 712 322.50
Clean H_2 JU max. contribution	EUR 2 712 322.50
Project period	1.1.2021–31.12.2024
Coordinator	Institut Jožef Stefan, Slovenia
Beneficiaries	Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile, AVL List GmbH, Bitron SpA, Commissariat à l'énergie atomique et aux énergies alternatives, École polytechnique fédérale de Lausanne, Haute école spécialisée de Suisse occidentale, SolydEra SA, Teknologian tutkimuskeskus VTT Oy, Università degli Studi di Salerno

https://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 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 AND MAIN ACHIEVEMENTS

- The second release of the updated MDPC tool, with enhanced communication functionalities concerning the local system controller and the excitation unit, has taken place. The tool is low-cost, yet with high computational performance.
- An innovative excitation module for stack perturbation with conventional sinusoidal and non-conventional discrete random binary signal has been developed.
- An extensive experimental campaign has been conducted on SOEC 4 short stacks, a segmented cell stack and two 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.
- First is the passive approach, utilising conventional signals and the simplified lumped models of the stack and system.
- Second is the active approach, which requires additional perturbation of the stack to get the complete fingerprint of the stack dynamics in terms of the electrochemical impedance spectra. The spectra are further deconvoluted and interpreted by using equivalent circuit models.
- A real-time optimisation (RTO) strategy for operating solid oxide electrolysis 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 the RTO solution approach. The first simulation results have been obtained using 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

An application for a project extension has been made. The main activities will be focused on the final integration of the MDPC tool and its validation on the two 70-cell SOEC stacks and a 25-cell rSOC stack.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?	SOA result achieved to date (by others)	Year for reported SOA result
MAWP addendum (2018–2020)	Q & M cost	€/(kg/day)/year	120	⚙	N/A	N/A
	Availability	%	98		95	2022
	Electrical consumption at rated capacity	kWh/kg H_2	39		40–45	2022

REDHY

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

Project ID	101137893
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	HORIZON-JTI-CLEANH2-2023-01-01: Innovative electrolysis cells for hydrogen production
Project total costs	EUR 2 998 988.75
Clean H_2 JU max. contribution	EUR 2 990 238.75
Project period	1.1.2024– 31.12.2027
Coordinator	Deutsches Zentrum für Luft- und Raumfahrt EV, Germany
Beneficiaries	Centre national de la recherche scientifique, Consiglio Nazionale delle Ricerche, Cutting-Edge Nanomaterials UG Haftungsbeschränkt, Industrie De Nora SpA, Uniresearch BV, Universitat Politècnica de València

https://cordis.europa.eu/project/id/101137893

PROJECT AND GENERAL OBJECTIVES

The REDHY project 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 SOA electrolysers. REDHY is entirely free of critical raw materials (CRMs) 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 an elevated current density (1.5 A/cm^2 at E_{cell} 1.8 V/cell) at low temperature (60 °C) and suitable hydrogen output pressure (15 bar). The project'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 h and achieve technology readiness level 4.

NON-QUANTITATIVE OBJECTIVES

- Develop highly efficient and durable materials that are free of CRMs and fluorine for the REDHY technology to a large-area short stack (five cells) with an active surface area of > 100 cm^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.
- 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 H_2 or less by implementing highly reversible, stable redox mediators with enhanced kinetics.
- Demonstrate a drastic reduction in interface resistance across all cell components, leading to energy efficiencies of > 82 %.
- Demonstrate the decoupling of oxygen and hydrogen production and enable the REDHY system to operate at a minimum 5 % of partial-load operation (nominal load 1.5 A/cm^2) without exceeding 0.4 % H_2 concentration in O_2.
- Demonstrate that the REDHY technology is capable of performing efficient and direct seawater electrolysis.
- Integrate the short stack into a prototype full system.
- Demonstrate the operation of the REDHY electrolyser at 1.5 A/cm^2 with electricity consumption of 48 kWh/kg over at least 1 200 hours of operation with a degradation of 0.1 %/1 000 h.

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 concentration in O_2	%	0.4		N/A	N/A
SRIA (2021–2027)	Current density	A/cm²	1.5		0.6	2020
	Degradation	%/1 000 h	0.1	⚙	0.19	2020
	CAPEX	€/kW	400		900	2020
	Use of CRMs as catalysts	mg/W	0		2.5	2020
	Electricity consumption at nominal capacity	kWh/kg	48		55	2020

REFHYNE

CLEAN REFINERY HYDROGEN FOR EUROPE

Project ID	779579
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	FCH-02-5-2017: Demonstration of large electrolysers for bulk renewable hydrogen production
Project total costs	EUR 19 759 516.50
Clean H_2 JU max. contribution	EUR 9 998 043.50
Project period	1.1.2018–30.6.2024
Coordinator	SINTEF AS, Norway
Beneficiaries	Element Energy Limited, ERM France, ITM Power (Trading) Limited, Shell Deutschland GmbH, Shell Energy Europe Limited, Sphera Solutions GmbH, Stiftelsen SINTEF

https://refhyne.eu/

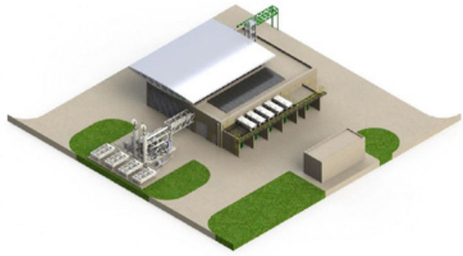
PROJECT AND GENERAL OBJECTIVES

The overall objective of the Refhyne project is to deploy and operate a 10 MW electrolyser in a power-to-refinery setting. Refhyne will validate the business model for using large-scale electrolytic hydrogen as an input to refineries, show the revenues available from primary and secondary grid balancing in today's markets and create an evidence base for the policy/regulatory changes needed to underpin the required development of this market. The electrolysers have been installed, the plant has been commissioned, and full operation and analysis are ongoing.

NON-QUANTITATIVE OBJECTIVES

The project aims to make recommendations for policymakers and regulators on measures required to stimulate the market for these systems. One of the key outputs of the project is a suite of reports providing the evidence base for changes to existing policies. This will include specific analysis focused on policymakers and recommending changes to existing policies.

The project aims to assess the legislative implications and regulations, codes and standards implications of these systems. Refhyne will produce an assessment of the consenting process for the system and any safety issues or codes and standards issues encountered.



PROGRESS AND MAIN ACHIEVEMENTS

The electrolyser has been tested and operated in different modes of operation, up to 10 MW. Full operation is ongoing, analysis is being done continuously and the first performance reports are expected in late winter 2024.

Lessons learnt from the design, construction and first operation have been summarised and published.

FUTURE STEPS AND PLANS

The system is in full operation, and the electrolyser will undergo several modes of operation, including dynamic response testing in grid connection mode. Refhyne will now undertake economic, technical and environmental analysis of the electrolyser's performance. The framework and models are in place, and analysis will begin once more system data are available.

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 and MAWP addendum (2018–2020)	Hot idle ramp time for H_2 production	seconds	1		2	2020
	Electricity consumption @ nominal capacity	kWh/kg	52		55	2020
	Degradation rate	%/1 000 h	0.15		0.19	2020
	CAPEX	€/(kg/day)	2 000		2 100	2020

Clean Hydrogen Partnership
Co-funded by the European Union

REFLEX

REVERSIBLE SOLID OXIDE ELECTROLYZER AND FUEL CELL FOR OPTIMISED LOCAL ENERGY MIX

Project ID	779577
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	FCH-02-3-2017: Reversible solid oxide electrolyser (rSOC) for resilient energy systems
Project total costs	EUR 2 999 575.48
Clean H_2 JU max. contribution	EUR 2 999 575.25
Project period	1.1.2018–30.6.2023
Coordinator	Commissariat à l'énergie atomique et aux énergies alternatives, France
Beneficiaries	Aktsiaselts Elcogen, Danmarks Tekniske Universitet, ENGIE, ENGIE Servizi SpA, Green Power Technologies SL, Parco Scientifico Tecnologico per l'Ambiente SpA, Sylfen, Teknologian tutkimuskeskus VTT Oy, Universidad de Sevilla

http://www.reflex-energy.eu/

PROJECT AND GENERAL OBJECTIVES

The Reflex project aimed to develop an innovative renewable energy storage solution, based on reversible solid oxide cell (rSOC) technology, that can operate in either electrolysis mode, to store excess electricity to produce H_2, or fuel cell mode, when energy exceeds local production levels, to produce electricity and heat from H_2 or other fuel. It has improved rSOC components (cells, stacks, power electronics, heat exchangers) and defined the system, its set points and advanced operation strategies.

PROGRESS AND MAIN ACHIEVEMENTS

- Enlarged cells were produced.
- The project has improved the stack for rSOC operation.
- The rSOC module design was completed and its assembly has started.
- The cold site acceptance test and hot site acceptance test have been performed.
- Prior to the start of the two Reflex modules, 5 632 hours of operation were performed on the alpha prototype and 135 full cycles were successfully applied from one mode to the other over the 3 372 hours of operation above 650 °C.
- Progress in terms of the six project objectives is reported below.

Objective 1. Enhance system components for efficient reversibility in functional environments.

- Optimisation and manufacturing of cells, stacks and heat exchangers completed.

Objective 2. Reduce losses in electrical, gas and heat management at the system level.

- Work on power electronics completed, with the best efficiency achieved in the DC/DC converter laboratory, at 96 %.
- Balance-of-plant components integrated into alpha prototype for validation before implementation in Reflex modules.

Objective 3. Define dynamic and smart switching strategies in full operational environment.

- Alpha prototype tests conducted to determine operating limits of stacks and logic of transitions between modes.
- Algorithms ported to Reflex system validated in 2023 and to be tested in 2024.

Objective 4. Demonstrate the whole system up to technology readiness level 6.

- System installed in Cheylas, France, with reduced number of modules.
- Electrolysis power of 55 kW for 10 Nm³/h of H_2 (10 kW in fuel cell mode) and thermal production of 6 kW achieved.

Objective 5. Provide hydrogen, electricity and heat with relevant costs for application.

- Maximum acceptable capital expenditure and operational expenditure defined for rSOC technology to be competitive on total cost of ownership.

Objective 6. Design a business model for the whole value chain.

- Most promising use cases for rSOC systems identified for power-to-power in the building sector.

FUTURE STEPS AND PLANS

The project has finished.

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	Cell active area	cm²	200	200	✓	128	2021
	Power electronic efficiency	%	95	96		88	2019
	Durability in SOEC step during rSOC operation at 0.58 A/cm² and SC = 68 %	%/1 000 h	2	1.2		2.3 for current densities of 0.6–0.7 A/cm² and SC = 50 %	2015
	Power modulation SC = 80 %	%	50–100 in SOFC, 70–100 in SOEC	58–100 in SOEC, 13–100 in SOFC (natural gas) and 23–100 in SOFC (H_2)		57–100 in SOEC	2019
	Current density in SOEC mode	A/cm²	1.2	N/A		1.15 A/cm² at 750 °C; 1 A/cm² at 800 °C	2015–2016

SEAL-HYDROGEN

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

SEALHYDROGEN

Project ID	101137915
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	HORIZON-JTI-CLEANH2-2023-01-01: Innovative electrolysis cells for hydrogen production
Project total costs	EUR 3 000 048.75
Clean H_2 JU max. contribution	EUR 3 000 000.00
Project period	1.1.2024–31.12.2026
Coordinator	Universitat de València, Spain
Beneficiaries	Forschungszentrum Jülich GmbH, HORIBA France SAS, Matteco Team SL, Siemens Energy Global GmbH & Co. KG

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. The project proposes a multidisciplinary approach to develop an efficient and highly durable alkaline water electrolysis stack (six cells) able to compete at the highest level with classic anion-exchange membrane and polymer electrolyte membrane electrolysers. A reliable method based on Raman spectroscopy will be developed for the precise determination of electrode stability, offering an appropriate quality control of great interest to both research and industry.

NON-QUANTITATIVE OBJECTIVES

The novelty of our technology lies in the:

- large-scale development of affordable formulations of layered double hydroxide (LDH) catalytic materials that have outstanding oxygen evolution reaction values, are made of non-toxic low-cost elements, are free of critical raw materials and can be mass-produced, while maintaining a circular economy approach thanks to a patented, environmentally sustainable synthetic route;
- development of triple-phase boundary electrodes (catalyst-support-ionomer) structures with improved thermomechanical stability;
- development of novel separator electrode assemblies with integrated components (porous transport electrodes);
- demonstration of the use of cutting-edge *in operando* Raman-spectroscopic techniques to characterise the intrinsic chemical activity and stability of catalysts.

The best-performing lab-scale cell components developed will be merged into an inexpensive, innovative electrolysis single cell (technology readiness level 4). A six-cell stack will be assembled to test and validate the potential of SEAL-Hydrogen's innovative approaches to overcome the main challenges of modern water electrolysis technologies. The involvement of manufacturing companies will ensure that manufacturability requirements are followed from the very beginning to prepare for further scale-up of the validated solution.

PROGRESS AND MAIN ACHIEVEMENTS

UVEG achieved the synthesis of various binary and ternary LDHs with different transition metal. Chemical and morphological characterisation is ongoing; electrochemical tests will follow. Matteco is focusing on scaling up NiFe LDHs to the kg scale, with plans to scale up other LDHs based on results from partners. Matteco achieved growth of a large-surface-area electrode for testing. HIERN undertook a study of the dissolution of NiFe LDHs through a scanning flow cell coupled to an inductively coupled plasma mass spectrometer, showing promising preliminary results on Matteco LDH stability. Construction of the stack test station was initiated. The design is finalised, including specifications on Ni substrate properties for the constructed stack.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
SRIA (2021–2027)	Electricity consumption in stacks	kWh/kg	48 (1.9 V at 0.8 A/cm²)	N/A	
	CRM	mg/W	< 0.3	0.3 mg/W	
Project's own objectives	Interface resistance	-	1.9 V at 0.8 A/cm², 48 kWh/kg	N/A	
	Partial-load operation	%	0.05	N/A	
Project's own objectives and SRIA (2021–2027)	Stability (in terms of current)	A/cm²	1	N/A	

X-SEED

EXPERIMENTAL SUPERCRITICAL ELECTROLYSER DEVELOPMENT

Project ID	101137701
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	HORIZON-JTI-CLEANH2-2023-01-01: Innovative electrolysis cells for hydrogen production
Project total costs	EUR 2 989 495.00
Clean H_2 JU max. contribution	EUR 2 989 495.00
Project period	1.1.2024–30.6.2027
Coordinator	Acondicionamiento Tarrasense Associacion, Spain
Beneficiaries	Danmarks Tekniske Universitet, Industrie De Nora SpA, Particular Materials SRL, Snam SpA

https://cordis.europa.eu/project/id/101137701

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 (SPWCs) (> 374 °C, > 220 bar), generating high-quality H_2 at pressure over 200 bar. Novel catalysts and electrodes are designed, synthesised and characterised to ensure high levels of efficiency. Multiscale modelling 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 %/1 000 h). X-SEED also integrates circularity and sustainability assessments in decision-making, limiting the use of critical raw materials (CRMs) (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. In conclusion, the X-SEED project's relevance and added value extend beyond the technological dimension: X-SEED will accelerate the H_2 ecosystem, supporting Europe in meeting climate targets and maintaining its leadership position as a technological developer, producer and exporter of green energy.

NON-QUANTITATIVE OBJECTIVES

- Maximise the efficiency, sustainability and stability of the innovative nanostructured catalysts and electrodes for anodes and cathodes based on Earth-abundant materials.
- Improve the efficiency, cost and durability of the electrolyser by developing an innovative cell and short stack that do not use an electrolysis membrane, based on use in SPWCs.
- Gather evidence of the sustainability and circularity benefits of the 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.

PROGRESS AND MAIN ACHIEVEMENTS

- The SPWC electrolyser framework was defined. It covers state-of-the-art (SOA) catalysts and electrodes, a survey of industrial waste water to be used as a source of catalysts and electrolytes and a survey of industrial thermal waste appropriated for the operation of the SPWC electrolyser (no Innovation Radar / no Horizon Results Platform).
- The SPWC cell and stack design was modelled using 2D and multiphysics simulation.
- The first batch of nanostructured catalysts stable at SPWCs was synthesised. Catalysts are based on perovskites, metal oxides and transition-metal-decorated nanoparticle structures.

FUTURE STEPS AND PLANS

- Selection of waste water suitable for catalyst synthesis via hydrothermal supercritical processes (continuous hydrothermal flow synthesis).
- Selection of electrolyte to use in the SPWC electrolyser.
- Selection of waste thermal energy from industries that is suitable to operate the SPWC.
- Electrochemical and physico-chemical characterisation of the catalyst and synthesis of improved ones.
- Electrode design and development based on high-stability materials and synthesised catalysts.
- Start of the design and preparation of the test bench to operate and evaluate the SPWC electrolysis cell.

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	Feedback received from experts	number	> 15		N/A	–
	Separation of products (O_2 and H_2)	% of H_2 at O_2 gas stream	< 4		Not reported for SPWC electrolyser	–
	High operational flexibility: load range	% (start-up and cold down time, seconds)	5–110 %, with fast start-up and cold down (< 600 seconds)		Load range is 5–120 % for PEMEL, 15–110 % for AWEL or 30–125 % for SOEL; the start-up and cold down time ranges from < 60 seconds for PEMEL to > 10 hours for SOEL	2020
	Synthesis and study	types of catalyst	3		N/A	–
	Assessments	number	3		N/A	–
	Electricity consumption @ nominal capacity	kWh/kg of H_2	42		47–66 for PEMEL and AWEL and 35–50 for SOEL at the stack level	2020
	Nominal power of a short-stack supercritical electrolyser integrated into five cells of 25 cm^2	kW	0.5		For the SPWC electrolyser, only a single cell has been tested	–
	Degradation rate < 1 %/1 000 h, demonstrated by ageing stress tests at the SPWC cell and stack levels	%/1 000 h	< 1		Not reported for the SPWC electrolyser	–
	Heat recovered	%	50		N/A	–
	Production capacity synthesis of catalysts using upscalable processes	kg/h	1		1 t per day is possible for different manufacturing techniques and types of catalyst	2018, 2016, 2017, 2011
	External interactions through social media, workshops and disclosure articles	number	5 000		N/A	N/A
	Cell and stack electrolyser work at current density	A/cm^2 at 1.8 V in SPWCs	3		35 A/cm^2; 3 A/cm^2 at 2.5 V	2023; 2022
	Performance loss in the electrochemical, thermal, and chemical ageing tests)	%/1 000 h	< 0.8		Not reported for SPWC electrolyser	–
	Reduction of electricity consumption in comparison with AWEL and PEMEL	% kg CO_2	20		Carbon footprint varies from 25 kg CO_2/kg H_2 (for AWEL and SOEL) to 20 kg CO_2/kg H_2 for SOEC, based on grid electricity consumption in Germany in 2018 (0.47 t CO_2/MWh)	2020
	Production of H_2 at > 200 bar	bar	> 200		30 bar at the cell level (PEMEL, AWEL); tests in SPWCs at 300 bar have been carried out	2020; 2022; 2022
	Interactions with end users	number	5		N/A	N/A
	Catalyst and electrodes with high electrolytic efficiency	mV η_{10} at NTP	< 100 for HER; < 150 for OER;		90 mV at η_{10} for HER and 150 mV η_{10} for OER	2021
	Potential cost of production	€/kg	3		Without optimisation, the production cost of supercritical electrolysis is USD 7.5/kg H_2; with CAPEX, cost of electricity, etc. optimised, high-pressure high-temperature water electrolysis is expected to produce H_2 at USD 3.10/kg	2021
	Scientific contributions	number	22		N/A	–
	Metals (Ni, Co, Cu, etc.) for the catalyst come from waste water	%	50		N/A	–
	Patents and exploitation of the materials and systems developed in related industrial sectors	number	2		N/A	N/A
	Non-use of Pt and Ru, decreased use of CRMs	mg/W	< 0.3		0	2021
	Catalysts with high surface areas	m^2/g	10		> 100 m^2/g	2020

EIC Green Hydrogen Portfolio Project

EIC FUNDED PROJECT
participating in the Clean Hydrogen JU
data collection exercise.

GH2

GREEN H2 PRODUCTION FROM WATER AND BIOALCOHOLS BY FULL SOLAR SPECTRUM IN A FLOW REACTOR

GH2

Project ID	101070721
Funding programme	HORIZON.3.1 – The European Innovation Council
PRR 2024	Pillar 1 – Renewable hydrogen production
Call topic	HORIZON-EIC-2021-PATHFINDERCHALLENGES-01-04: Novel routes to green hydrogen production
Project total costs	EUR 2 201 654.72
Clean H_2 JU max. contribution	EUR 2 201 654.72
Project period	1.10.2022–30.9.2025
Coordinator	Acondicionamiento Tarrasense Associacion, Spain
Beneficiaries	Crowdhelix Limited, Eidgenössische Technische Hochschule Zürich, Max-Planck-Gesellschaft zur Förderung der Wissenschaften EV, Pangaia Grado Zero SRL, Università degli Studi di Napoli Federico II, University College London, University of Hong Kong

https://www.gh2-project.eu/

PROJECT AND GENERAL OBJECTIVES

The project aims to harness solar technologies to produce green H_2 and valuable C_{2+} chemicals.

We expect to produce green H_2 with a quantum efficiency of > 60 % using bioethanol and water as feedstock.

The reaction will be purely driven by solar energy in well-integrated photocatalytic and infrared-driven reactors. The products will be separated using an advanced membrane separation unit.

We will harness the full solar spectrum to apply biomass derivatives oxidation rather than sluggish water oxidation to substantially speed up the reaction kinetics and increase efficiency. This will allow for the utilisation of the flow reactor principle to facilitate mass transfer. The project will also avoid using any critical raw materials as catalysts, thus reducing the material supply risk.

Objectives. The project aims to produce green hydrogen by harvesting solar energy and biomass, while simultaneously producing high-value chemicals as derivatives; construct a scalable production process that can be leveraged by multiple industries; produce green hydrogen at a cost comparable to that of fossil-derived H_2; and establish a H_2 production process that neither uses nor produces greenhouse gases.

NON-QUANTITATIVE OBJECTIVES

The project aims to develop a combined ultraviolet–visible-light catalyst, an infrared (IR) catalyst and a thermal catalyst to utilise the full solar spectrum (300–2 500 nm).

PROGRESS AND MAIN ACHIEVEMENTS

For the ultraviolet–visible-light catalyst, the project team achieved a remarkable early-stage success by adjusting the structure of the photocatalyst and the parameters of hydrogen production used with ethanol and generated a 70 % quantum yield in the light-driven production of hydrogen.

For the IR-driven catalyst, a flow reactor was designed to systematically investigate the ethanol-reforming potential under IR irradiation (> 700 nm). Under optimised conditions, the catalyst shows a hydrogen production rate of ~ 4.5 mmol h_{-1} and a high yield rate (~ 4.4 mmol h_{-1}) of the valuable oxidation product acetaldehyde, with a high selectivity of ~ 90 %.

FUTURE STEPS AND PLANS

Thus far, the reactions of each catalyst have been tested separately in batch or flow mode. In order to design the catalytic reactor, kinetic models are required to evaluate various reactor configurations and then build the most promising reactor.

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	Quantum efficiency high H_2 yield rate for IR catalysts using non-critical materials	mmol h_{-1}	> 1	N/A		0.004–2 mmol h_{-1}; generally, Pt is needed to achieve high performance in the reported results	2010–2023
	Selectivity co-production high-value chemicals	%	> 90	For IR catalysts, the main high-value chemical is acetaldehyde (91 %)		In photocatalysis, most research did not consider the oxidation products In thermocatalysis, the reforming products are mainly CO and CO_2 rather than valuable products	2010–2023