Clean Hydrogen Partnership

PROGRAMME REVIEW REPORT 2024

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Manuscript completed in November 2024

Luxembourg: Publications Office of the European Union, 2024

Cover image: Fokke Baarssen / stock.adobe.com

Print	ISBN 978-92-9246-438-7	ISSN 2443-602X	doi:10.2843/701255	EG-AA-24-001-EN-C
PDF	ISBN 978-92-9246-439-4	ISSN 2443-6038	doi:10.2843/261415	EG-AA-24-001-EN-N

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PROGRAMME REVIEW
REPORT 2024

EUROPEAN PARTNERSHIP

Co-funded by the European Union

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AEL	Alkaline electrolysis/electrolyser
AEMEL	Anion exchange membrane electrolysis/electrolyser
AWP	Annual working plan
BEV	Battery electric vehicle
BoP	Balance of plant
CAPEX	Capital expenditure
CCM	Catalyst coated membrane
CHP	Combined heat and power
CINEA	European Climate, Infrastructure and Environment Executive Agency
CMR	Catalytic membrane reactor
CRM	Critical raw materials
EHO	European Hydrogen Observatory
EHSP	European Hydrogen Safety Panel
EPC	Engineering, procurement and construction
EU	European Union
FC/FCS	Fuel cell/fuel cell system
FCEB	Fuel cell electric bus
FCET	Fuel cell electric truck
FCEV	Fuel cell electric vehicle
FCH JU	Fuel Cells and Hydrogen Joint Undertaking in the 7th R&I framework programme
FCH 2 JU	Fuel Cells and Hydrogen 2 Joint Undertaking under the H2020 R&I framework programme
FP7	EU 7th framework programme
GA	Grant agreement
H_2	Hydrogen
H2020	Horizon 2020
HDV	Heavy-duty vehicle
HE	Horizon Europe
HRS	Hydrogen refuelling station
HT	High temperature
IEC	International Electrotechnical Commission
IPCEI	Important projects of common European interest
ISO	International Organisation for Standardisation
JRC	Joint Research Centre of the European Commission
JU	Joint Undertaking
KOH	Potassium hydroxide
KPI	Key performance indicator
LCA	Life cycle assessment
LCOH	Levelised cost of hydrogen
LCSA	Life cycle sustainability assessment
LH2	Liquid hydrogen
LHV	Lower heating value

LOHC	Liquid organic hydrogen carrier
LT	Low temperature
MAIP	FCH JU multi-annual implementation plan (2008-2013)
MAWP	FCH 2 JU multi-annual work plan (2014-2020)
m-CHP	micro-CHP
MDPC	Monitoring, diagnostic, prognostic and control tool
MEA	Membrane electrode assembly
MHV	Material handling vehicles
NG	Natural gas
O_2	Oxygen
OEM	Original equipment manufacturer
OPEX	Operating expenses
P2P	Power-to-power
PCC	Proton conducting ceramic electrochemical cells
PCCEL	Proton conducting ceramic electrolysis/electrolyser
PDA	Project development assistance
PEM	Proton exchange membrane
PEMEL	Proton exchange membrane electrolysis/electrolyser
PEMFC	Proton exchange membrane fuel cell
PFAS	Perfluoroalkyl and polyfluoroalkyl substances
PGM	Platinum group metals
PNR	Pre-normative research
PSA	Pressure swing adsorption
PV	Photovoltaic
R&D	Research and development
R&I	Research and innovation
RCS	Regulations, codes and standards
RES	Renewable energy sources
rSOC	Reversible solid oxide cell
SBA	Single Basic Act
SME	Small and medium-sized enterprise
SMR	Steam methane reforming
SoA	State-of-the-art
SOC	Solid oxide cell
SOEC	Solid oxide electrolyser cell
SOEL	Solid oxide electrolysis/electrolyser
SOFC	Solid oxide fuel cell
SRG	State Representatives Group
SRIA	Strategic research and innovation agenda of the Clean Hydrogen JU
TCO	Total cost of ownership
TIM	Tools for innovation monitoring

TPRD	Thermal pressure relief device
TRL	Technology readiness level
	TRL 1 – basic principles observed
	TRL 2 – technology concept formulated
	TRL 3 – experimental proof of concept
	TRL 4 – technology validated in lab
	TRL 5 – technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
	TRL 6 – technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
	TRL 7 – system prototype demonstration in operational environment
	TRL 8 – system complete and qualified
	TRL 9 – actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies or in space)
TRUST	Technology Reporting Using Structured Templates

EXECUTIVE SUMMARY

Hydrogen is expected to play an important role in achieving the EU objectives of reducing greenhouse gas emissions by a minimum of 55 % by 2030 and reaching net-zero emissions by 2050. Research and Innovation (R&I) on hydrogen technologies is continuously supported by the EU. Fuel Cells and Hydrogen (FCH) and Fuel Cells and Hydrogen 2 (FCH 2) Joint Undertakings (JUs) demonstrated the potential of hydrogen as an energy carrier and of FCs as energy converters. The Clean Hydrogen JU, under the Horizon Europe programme, follows their legacy, focusing mainly on R&I in renewable hydrogen production, storage, distribution, end-uses and overarching research areas.

In order to ensure that the programme of the Clean Hydrogen JU is aligned with the strategy and objectives of its founding regulation, as well as to monitor progress in the research into and deployment of hydrogen technologies achieved by its projects, the JU performs, on an annual basis, the programme review exercise. This can be separated into four main activities: (a) the annual data collection exercise, (b) the annual programme technical assessment, (c) the *Programme Review Report* (i.e. the present report) and (d) the programme review days.

The Joint Research Centre of the European Commission (JRC) has been entrusted with the performance of the programme technical assessment based on the data collected from projects by the Programme Office (mainly through the TRUST platform and the project fiches). This assessment lies at the core of the *Programme Review Report*.

The 2024 annual programme technical assessment focuses on the 67 ongoing Horizon 2020 (H2020) projects of the JU from 2023 and the 85 Horizon Europe (HE) projects of the JU that have so far signed grant agreement (GA)s, distributed across eight pillars.

The projects in pillar 1 contribute to making hydrogen generation from (variable) RES technologies competitive and enabling the scale-up of these technologies to relevant levels. The main technology funded under this pillar is electrolysis. The JU still plays a leading role in the development of PEMEL technology, having made considerable advances towards reaching the 2024 and 2030 KPIs and showing a strong decrease in the use of CRMs. Also, clear progress has been made regarding the durability of Solid Oxide Electrolysers (SOELs).

Hydrogen storage and distribution will play a vital role in allowing further penetration of renewable hydrogen in Europe. The SRIA of the Clean Hydrogen JU favours a pluralistic approach to technologies that will serve as building blocks for an EU-wide logistical infrastructure. Under pillar 2, underground storage and hydrogen transport and storage solutions in the form of liquid hydrogen or chemical carriers have been receiving renewed attention since 2020.

Projects for transport end-uses (pillar 3) reflect the significant efforts of the previous JU to develop, validate and demonstrate technologies for FC material handling vehicles (MHV), buses and passenger cars, which are now considered market ready. The transfer of technical knowledge from those applications is already allowing further development of solutions for in heavy-duty vehicles (HDV), off-road and industrial vehicles; and train, waterborne and aviation applications.

Clean heat and power projects (pillar 4) continue the development of renewable and flexible heat and power generation systems for different end-users. Significant progress has already been demonstrated in both stationary PEMFCs and SOFCs. On top of that, a new research area has been introduced, with six projects focusing on hydrogen, ammonia and natural gas (NG) combustion in gas turbine combustors and boiler burners and investigating how existing installations and machinery using fossil fuels can be retrofitted to become hydrogen ready.

Tailored Life Cycle Assessment (LCA) guidelines for FC and hydrogen technologies have been developed (pillar 5) to accurately assess their environmental impact. Education and training tools and methods addressing the specialised knowledge and skills needs of a broad range of users have been developed under the Clean Hydrogen JU programme (pillar 5). Among recent achievements, the first university master's (MSc) programme dedicated in its entirety to FC and hydrogen themes has been accredited.

The hydrogen valley concept has become a key instrument for the European Commission to scale up hydrogen technology deployment and establish interconnections between hydrogen ecosystems. The REPowerEU plan has allocated an additional EUR 200 million to the Clean Hydrogen JU, aiming to double the number of hydrogen valleys by 2025. The Clean Hydrogen JU has already funded or continues to fund 16 hydrogen valleys so far (pillar 6).

European companies and research organisations are leaders in many segments along the hydrogen supply chain, which gives Europe a competitive advantage over other key players such as Japan, South Korea, the USA and, more recently, China. Additional support is necessary for Europe to continue leading the way (pillar 7).

The programme needs to tackle strategic research challenges by funding deep innovation activities (pillar 8). New projects aim to address research areas ranging from establishment of eco-design guidelines and environmentally friendly manufacturing methods to energy-efficient and lower-emission processes involving artificial intelligence, as well as development of diagnostic models and standardisation of test procedures, with a focus on reducing the cost of electrolysers.

1. INTRODUCTION

Climate change and environmental degradation are an existential threat to Europe and the world. The production and use of energy account for more than 75 % of the EU's greenhouse gas emissions. Decarbonising the EU's energy system is therefore critical to reach our 2030 climate objectives and the EU's long-term goal of achieving carbon neutrality by 2050. The European Green Deal and the Fit for 55 initiatives will help to overcome these challenges by transforming the EU into a modern, resource-efficient and competitive economy.

Hydrogen is expected to play an important role in achieving the EU objectives of reducing greenhouse gas emissions by a minimum of 55 % by 2030 and reaching net-zero emissions by 2050. Apart from the current uses as feedstock, hydrogen is also an energy carrier and can be used as a fuel without any CO_2 emissions, which are the main contributor to the greenhouse effect. Clean hydrogen can contribute to decarbonising hard-to-abate sectors, energy-intensive industries (such as steel, chemicals and cement) and the transport sector (e.g. heavy-duty vehicles (HDV), rail and maritime), as well as the power sector.

Research and innovation (R&I) on hydrogen technologies are continuously supported by the EU. Fuel Cells and Hydrogen (FCH) and Fuel Cells and Hydrogen 2 (FCH 2) joint undertakings (JUs) demonstrated the potential of hydrogen as an energy carrier and of fuel cells (FCs) as energy converters. Following this legacy, the Clean Hydrogen Joint Undertaking (Clean Hydrogen JU)[1] continues to support R&I activities on hydrogen technologies and applications, focusing mainly on increasing activities in relation to renewable hydrogen production, storage, distribution and end-uses. Thanks to the JU's continuous efforts, several technologies have reached or come closer to maturity, and high-profile projects have been developed in promising applications, closing the knowledge gap and supporting uptake in the European energy system. Moreover, the EU has achieved global leadership in certain future technologies, notably electrolysers, hydrogen refuelling stations (HRS) and megawatt-scale FCs.

The multi-annual programme of the Clean Hydrogen JU is described in its Strategic Research and Innovation Agenda (SRIA)[2]. Compared to the Multi-Annual Work Programmes (MAWPs)[3] of its predecessors, it contains a much broader set of activities in all areas and applications where hydrogen is expected to play a role, across energy, transport, building and industrial end-uses. Simultaneously, with many more research programmes targeting the deployment and demonstration of hydrogen technologies, it is expected that the Clean Hydrogen JU will closely collaborate with other partnerships, and in synergy with other EU, national and regional research funding programmes, it will help strengthen and integrate EU scientific capacity to accelerate the development and improvement of advanced, market-ready clean hydrogen applications.

The Clean Hydrogen JU has an initial budget of EUR 1 billion for the period 2021-2027, complemented by at least an equivalent amount of private investment coming from the private members of the JU and an additional EUR 200 million aiming to double the number of hydrogen valleys across Europe as part of REPowerEU[4]. Additional contributions from the UK, a country associated to HE, are expected to further increase the initial JU budget.

1 https://www.clean-hydrogen.europa.eu/index_en

2 Strategic Research and Innovation Agenda 2021-2027.

3 Multi-annual Implementation Plan (MAIP) for 2008-2013 under FP7, Multi-Annual Work Programme (MAWP) for 2014-2020 under H2020.

4 REPowerEU Plan, COM(2022) 230.

2. PURPOSE AND SCOPE OF THE PROGRAMME REVIEW

The purpose of the annual programme review is to ensure that the Clean Hydrogen JU programme remains aligned with the strategy and objectives set out in the Single Basic Act (SBA)[5], further elaborated in the SRIA 2021-2027. The programme review exercise, inaugurated in 2011, was carried out until 2016 by external experts from research and industry, both European and non-European, as well as by members of the FCH 2 JU Scientific Committee, with the aim of assessing progress towards the multi-annual targets for FC and hydrogen technologies in Europe based on specific and quantitative key performance indicators (KPIs) described in the multi-annual plans, covering parameters such as cost, durability and performance.

Since 2017, following up on a recommendation[6] made by the Internal Audit Service of the European Commission, the JRC has been entrusted with the programme review exercise as part of its activities under the multi-annual framework contract signed with the JU on the basis of a declaration of confidentiality and conflict of interest. The JRC performs the annual programme technical assessment focusing on the major outputs and impact of the projects, the performance of the programme against the SRIA KPIs and the difficulties encountered by the projects. Moreover, both for the programme overall and each pillar separately, it identifies research gaps and provides recommendations.

The data collection of relevant information from projects is carried out by the Programme Office using multiple sources, including the Technology Reporting Using Structured Templates (TRUST)[7] platform, project deliverables and an additional online survey. As of 2024, the survey has been replaced by another much more suitable software solution using the Suite CRM application that contains the project's fiches[8]. A database has been created that will provide the necessary input for the next step: the deployment of the new TRUST application under the Clean Hydrogen Knowledge Hub platform[9], which will incorporate all the project data and information into a single database. As of 2025, the data collection exercise is expected to be performed through the Knowledge Hub platform.

5 Council Regulation (EU) 2021/2085 of 19 November 2021 establishing the Joint Undertakings under Horizon Europe (https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R2085).

6 Final audit report on performance management of the FCH 2 JU activities (Internal Audit Service report: IAS.A2-2016-FCH 2 JU-003).

7 https://www.clean-hydrogen.europa.eu/knowledge-management/annual-data-collection_en

8 https://www.clean-hydrogen.europa.eu/knowledge-management/annual-data-collection_en#project-fiche

9 The Clean Hydrogen Knowledge Hub will be a unique digital platform that will encompass and enrich information and data of the available tools/platforms of the JU. Its development began in 2024, following a public Call for Tenders.

3. ANNUAL PROGRAMME TECHNICAL ASSESSMENT BY JRC

The annual programme technical assessment is one of the main activities performed by the JRC under the framework contract. It includes analysis of the data provided by the Clean Hydrogen JU and knowledge acquired by the JRC experts and extensive exchanges with the JU staff, especially the project officers and the knowledge management team, and culminates in the delivery of a report for internal use. Apart from the main takeaways as regards the main impacts and outcomes coming from the projects, the report also includes an analysis of gaps in relation to the SRIA objectives and provides recommendations to improve the implementation of the programme. The current programme review report relies mainly on the content of the annual programme technical assessment report, and this content is reflected mainly in Chapter 5 and the Annex.

The 2024 annual programme technical assessment includes all projects up to the 2020 calls for proposals that were ongoing[10] in the period January 2023 to March 2024. It also includes the projects of the 2022 calls[11] – the first under HE – as most of those projects had signed their GAs by the end of 2022 and initiated activities in early 2023. Finally, although the agreements for the projects of the 2023 call[12] were signed too recently to have produced any outcomes, they have also been analysed based on the content of their project fiches in order to give them visibility and forecast their possible impacts against the related SRIA targets.

The current annual programme technical assessment therefore covers 152 projects: 67 H2020 projects[13] and 85 HE projects, of which 32 projects are from the 2023 call. All projects considered for this year's assessment have run for more than 12 months, except those from the 2023 call. In line with the new programme structure of the Clean Hydrogen JU explained in the SRIA, all projects have been assigned to eight pillars that cover a wide range of topics and related activities:

- Pillar 1: Renewable hydrogen production
- Pillar 2: Hydrogen storage and distribution
- Pillar 3: Hydrogen end-uses: transport applications
- Pillar 4: Hydrogen end-uses: clean heat and power
- Pillar 5: Cross-cutting issues
- Pillar 6: Hydrogen valleys
- Pillar 7: Supply chain
- Pillar 8: Strategic research challenges.

Moreover, as part of the legacy projects of H2020, the Clean Hydrogen JU is continuing certain activities and applications. To better map the different current and possible future activities of the JU, its programme (including ongoing legacy projects) can be further mapped into a set of research areas[14], which group projects covering related topics. This split is presented in Table 1 below.

10 'Ongoing' means between project start date and project end date.

11 HORIZON-JTI-CLEANH2-2022-1 and HORIZON-JTI-CLEANH2-2022-2 calls: https://www.clean-hydrogen.europa.eu/call-proposals-2022_en

12 HORIZON-JTI-CLEANH2-2023 call: https://www.clean-hydrogen.europa.eu/call-proposals-2023-closed_en

13 Including COSMHYC XL, although it didn't participate in the annual data collection.

14 These research areas are the basis of the annual programme technical assessment performed by JRC.

Table 1: Research areas and topics per pillar of projects reviewed

PILLARS	RESEARCH AREAS	RESEARCH TOPICS
1) Renewable hydrogen production	1 – LT electrolysis	Projects targeting AEL, PEMEL and AEMEL
	2 – HT electrolysis (incl. co-electrolysis)	Projects targeting SOEL and PCCEL
	3 – Other hydrogen production methods	Projects covering hydrogen production through solar-driven thermochemical, photocatalytic and waste gasification processes
2) Hydrogen storage and distribution	4 – Aboveground storage	Projects addressing optimisation and deployment of large-scale, aboveground, solid-state storage solutions
	5 – Underground storage	Projects targeting the feasibility, risks and impact of H2 underground storage, and large-scale demonstration
	6 – H2 in the NG grid	Projects assessing the effect of H2 on transmission and distribution in NG pipelines
	7 – Liquid H2 carriers	Projects focusing on the improvement of the roundtrip efficiency of conversion and system cost
	8 – Compression, purification and metering solutions	Projects demonstrating compression and distribution, material research on PCCs and purification concepts
	9 – HRSs	Projects addressing refuelling capacity, reliability and availability issues indicated by operation of HRSs, including for LH2 for heavy-duty applications
	10- Hydrogen transportation (pipelines, road transport and shipping)	Projectsin 2023 focusing on the improvement of the transportation and storage of LH2 in shipping
	11 – Hydrogen distribution (pipelines)	*No ongoing projects in 2023*
	12– Liquid hydrogen storage	Development of novel insulation concepts enabling the safe, cost- and energy-efficient storage of large quantities of LH2

PILLARS	RESEARCH AREAS	RESEARCH TOPICS
3) Hydrogen end-uses: transport applications	13 – Building blocks	Projects focusing on material, design and system optimisation for LT and HT PEMFC
	14 – HDVs	Projects addressing optimisation of BoP architecture design to meet HDV needs
	15 – Waterborne applications	Projects focusing on improving access to the market for hydrogen, its derivatives and FCs, including large-scale demonstrations
	16 – Rail applications	Projects with the objective of enabling hydrogen to be recognised as the leading option for trains on non-electrified or partially electrified routes
	17 – Aviation applications	Projects addressing optimisation of BoP component and architecture design to meet aviation needs
	18 – Buses/coaches	Projects with the objective of improving the deployment of hydrogen in this segment
	19 – Cars	Projects with the objective of improving the deployment of hydrogen in this segment
4) Hydrogen end-uses: clean heat and power	20 – m-CHP	Projects exploring the deployment of PEMFCs and SOFCs for micro-cogeneration
	21 – Commercial-sized CHP	Demonstration projects for commercial-sized CHP using SOFCs and HT PEMFCs
	22 – Industrial-sized CHP	Projects exploiting SOFC and PEMFC technology at industrial scale
	23 – Off-grid/back-up/genset	Demonstration projects exploring the application of PEM, solid oxide and alkaline hydrogen technologies (FCs and electrolysers)
	24 – Next-generation degradation and performance and diagnostics	Exploration projects for utilisation of biogas fed with a SOFC CHP system and use of electrochemical impedance spectroscopy technology for monitoring and diagnostic purposes
	25 – Turbines, boilers and burners	Research projects to allow low-NOx combustion of hydrogen-enriched fuels (up to 100%) at high-pressure conditions for new or existing gas turbine combustion systems
5) Cross-cutting issues	26 – Sustainability, LCSA, recycling and eco-design	Projects addressing needs for the definition of guidelines for sustainability assessment
	27 – Education and public awareness	Projects aiming to increase understanding and knowledge of hydrogen technology at public and educational level (schools/universities)
	28 – Safety, PNR and RCS	Projects focusing on improving knowledge of risk of hydrogen utilisation and definition of protocols for permitting and measurement
	29 – International cooperation	Enabling R&I co-operation with African countries on hydrogen

PILLARS	RESEARCH AREAS	RESEARCH TOPICS
6) Hydrogen valleys	30 – Small-scale valleys	Projects aiming to develop island and integrated micro-hydrogen systems to showcase the potential of hydrogen technologies and prepare for future upscaling
	31 – Large-scale valleys	Projects aiming to demonstrate integrated cross-border or interregional hydrogen systems when favourable industrial or geographical conditionsexist
7) Supply chain	32 – Manufacturing for stationary applications	Projects aiming to advance high-volume production techniques and quality control measures for manufacturing SOFC components and stacks
	33 – Manufacturing for transport applications	*No ongoing projects in 2023*
	34 – CRMs	*No ongoing projects in 2023*
8) Strategic research challenges	35 – Strategic research challenges	Projects aiming to develop a sustainable European supply chain of materials, components and cells that is less reliant on CRMs and with lower environmental footprint and costs and higher performance and durability

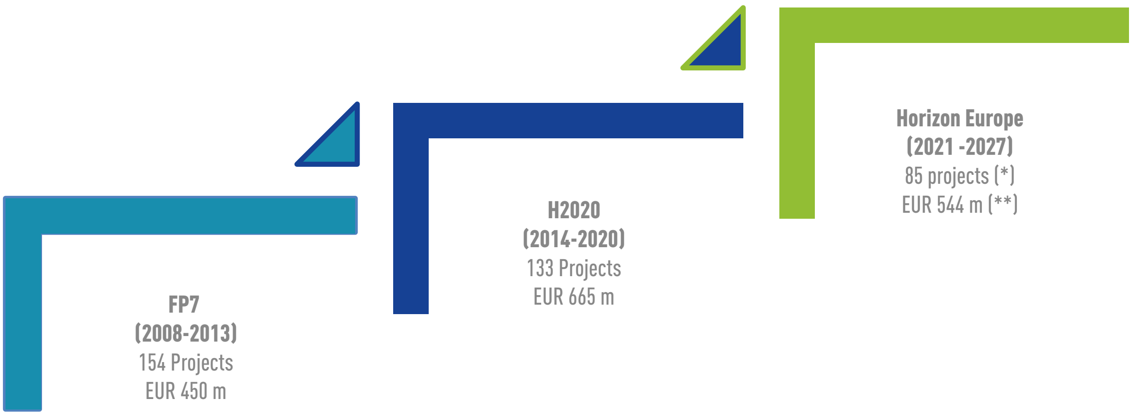
4. OPERATIONAL BUDGET IMPLEMENTATION

4.1. OVERVIEW

The Clean Hydrogen JU, established under the HE programme, succeeded the successful FCH 2 JU with a clear mandate to build on the legacy and output of the previous programmes and to ensure continuity by taking over all pending contracts of the FCH and FCH 2 JUs, including GAs. The previous JUs had a significant impact under the FP7 and H2020 programmes, investing significantly in hydrogen technology R&I; the cumulative EU operational budget invested in 287 hydrogen and FC projects through signed GAs reached a total of EUR 1.12 billion. An additional operational budget of EUR 17.25 million was allocated to the procurement of studies.

In line with the ambition and the objectives set out for the Clean Hydrogen JU, the EU financial contribution to the JU will be up to EUR 1 billion[15], which will be complemented by the affiliated entities of the rest of the members of the Clean Hydrogen JU, who will provide a total contribution of at least EUR 1 billion, as mandated by Articles 76 and 77 of the SBA. Also, the European Commission will top up the overall budget of the Clean Hydrogen JU with additional funding of EUR 200 million, aiming to double the number of hydrogen valleys under the REPowerEU plan. As a result of the ongoing implementation of the new programme, 85 projects from the 2022 and 2023 calls have already signed GAs[16] for an overall commitment of EUR 544 million (out of the EUR 1.2 billion operational budget for the period to 2027). The operational budget has been topped up by an additional EUR 5.61 million for the procurement of studies. Figure 1 presents the extent of the overall implementation of the Clean Hydrogen JU programme, including the legacy of previous programmes, in 2023.

Figure 1: EU contribution to the implementation of MAIP 2008-2013, MAWP 2014-2020 and SRIA 2021-2027



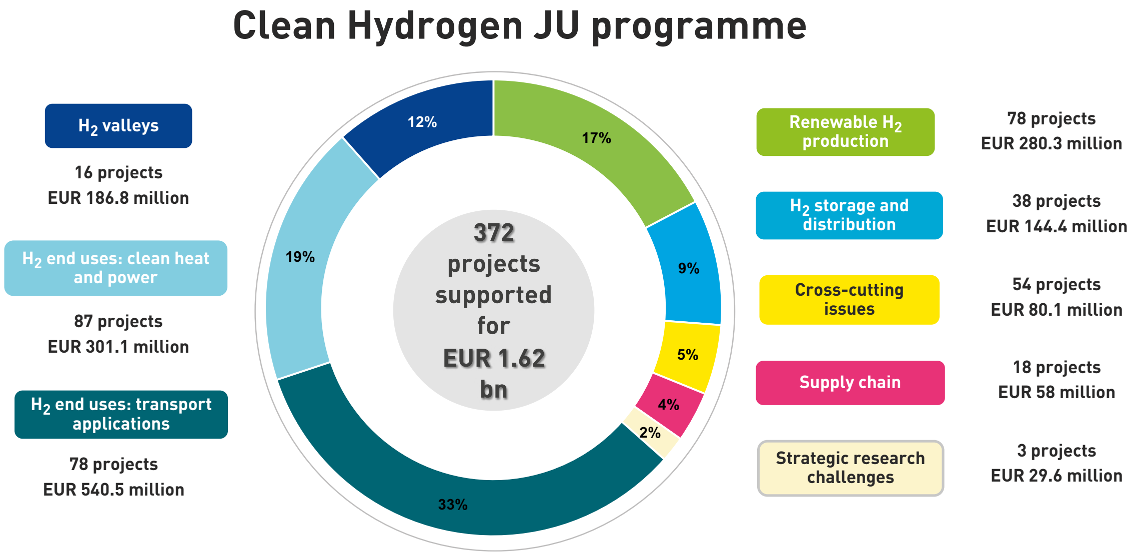
(*) Projects with signed GAs (2022 and 2023 calls).
(**) Out of EUR 1.2 billion of the overall programme operational budget, including funding foreseen for hydrogen valleys from the REPowerEU plan.
Source: Clean Hydrogen JU.

15 This amount is to be complemented by at least an equivalent amount of private investment (from the private members of the JU), raising the total budget to more than EUR 2 billion.

16 Two projects of the 2023 call were not included in this programme review report, as they had not signed their GAs within the period covered by the report.

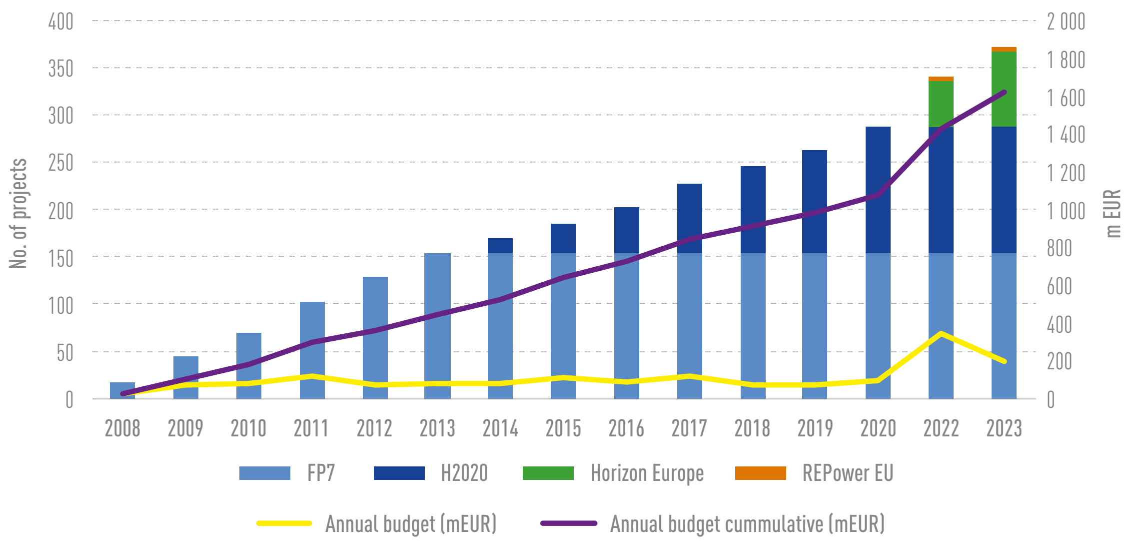
The first calls under the Clean Hydrogen programmes took place in 2022 and 2023, with an increased annual operational budget compared to the previous programmes, partially due to the frontloaded implementation of the current JU programme. These calls have substantially increased the overall EU financial contribution of the JU to EUR 1.62 billion, with a total of 372 concluded and ongoing projects. Figure 2 and Figure 3 present the breakdown of the projects and the operational budget committed/distributed for their implementation per SRIA pillar and per year between 2008-2023.

Figure 2: Projects supported by the Clean Hydrogen JU per pillar and annual financial contribution (2008-2023)



Source: Clean Hydrogen JU.

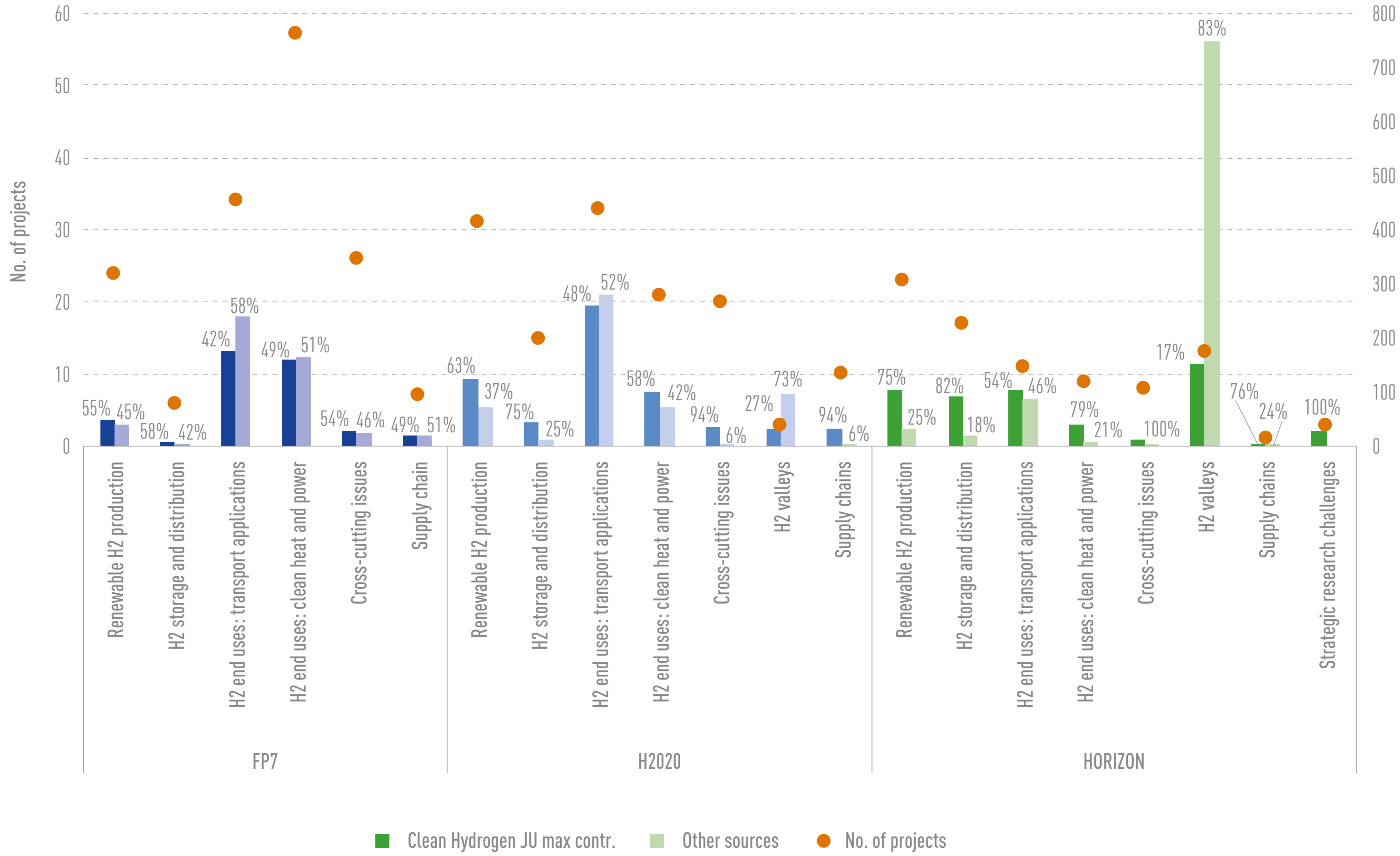
Figure 3: Annual financial contribution of the Clean Hydrogen JU (2008-2023)



Source: Clean Hydrogen JU.

Apart from the significant EU financial contribution through the Clean Hydrogen JU legacy and current programme, the private sector has also contributed additional financial resources to the implementation of the programme and to support activities of projects in different R&I areas, multiplying the impact and support to hydrogen and FC technologies. The overall financial contribution aggregated per programme and review pillar and divided among the different sources of funding is highlighted in Figure 4.

Figure 4: Number of projects and financial contribution of both Clean Hydrogen JU and private funding (utilised or planned) per SRIA pillar (2008-2023)

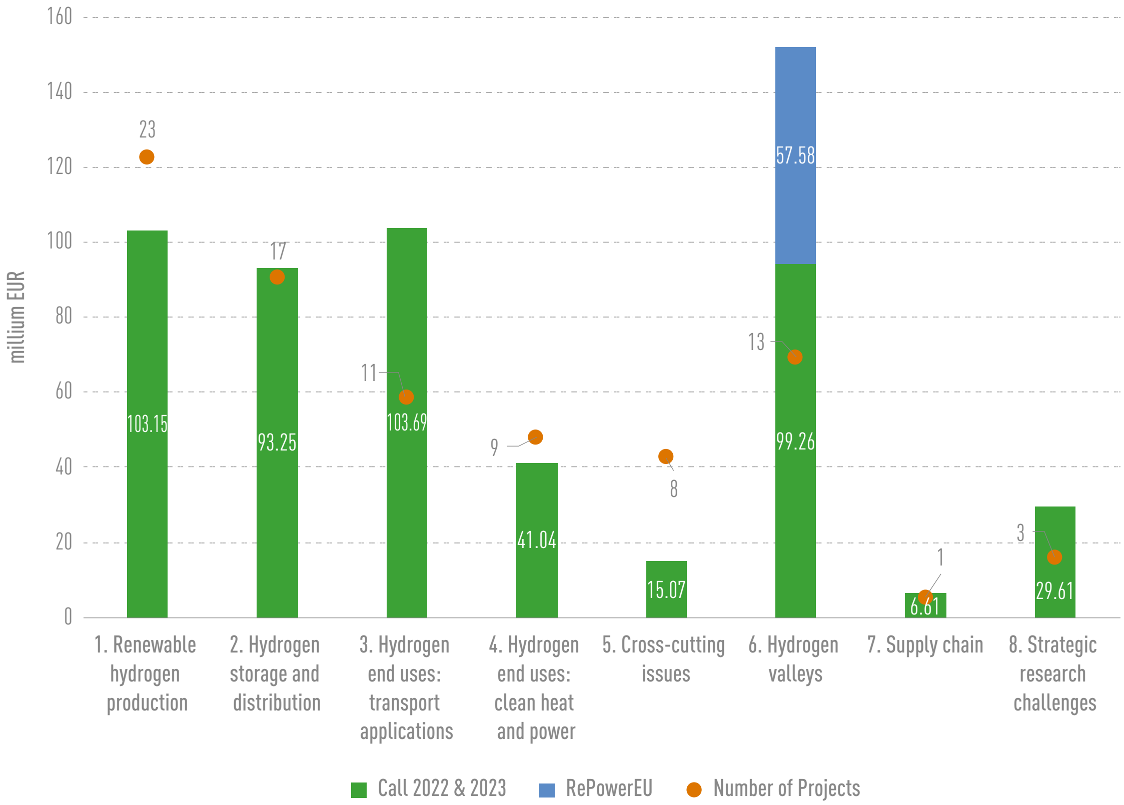


Source: Clean Hydrogen JU.

4.2. CALLS 2022 AND 2023

As already mentioned, the implementation of the JU programme is frontloaded; together with the 2024 call, an overall commitment of over EUR 700 million (out of EUR 1.2 billion) will have been made through GAs with projects and other operational activities related to the programme, with EUR 544 million already committed to 85 projects from the 2022 and 2023 calls. In terms of operational budget per pillar, the 13 hydrogen valley projects have the highest commitment: EUR 94.26 million plus EUR 57.58 million from the additional REPowerEU plan budget of EUR 200 million. The overall commitment linked to the projects from the 2022 and 2023 calls per SRIA pillar and the number of projects already formalised into GAs under HE are shown in Figure 5.

Figure 5: Financial contribution of Clean Hydrogen JU and number of projects from 2022 and 2023 calls with signed GAs per SRIA pillar



Source: Clean Hydrogen JU.

4.3. CALL 2024

A new call for proposals was published on 18 January 2024[17] and Gas are expected to be signed for a bundle of new projects by the end of 2024 for a total JU operational budget of up to EUR 173.5 million[18]. The 2024 call covers 20 R&I topics across the hydrogen value chain and horizontal aspects, including:

- Renewable hydrogen production: 5 topics, EUR 25 million;
- Hydrogen storage and distribution: 5 topics, EUR 27 million;
- Hydrogen end uses: transport applications: 4 topics, EUR 19 million;

17 https://www.clean-hydrogen.europa.eu/call-proposals-2024-closed_en

18 According to the annual work programme 2024: https://www.clean-hydrogen.europa.eu/document/download/7afb381f-af2a-4840-a46a-8a1c608c130b_en?filename=Clean%20Hydrogen%20JU%20AWP%202024%20-%20all%20chapters_Final_For_Publication.pdf

- Hydrogen end uses: clean heat and power: 2 topics, EUR 9 million;
- Cross-cutting issues: 2 topics, EUR 4.5 million;
- Hydrogen valleys: 2 topics, EUR 29 million (+ EUR 60 million top-up from REPowerEU plan investment).

4.4. PROGRAMME REVIEW PROJECT CLASSIFICATION

The programme review exercise includes all the projects ongoing in 2023 (partially or for the whole year). Aside from the legacy of mature H2020 projects still ongoing or ended in 2023, the HE projects of the 2022 and 2023 calls are reviewed for the first time by the JRC under the current programme review exercise. As many of them are still not mature enough to have progressed significantly towards their objectives, this report will briefly present their concepts and expected impacts to provide perspective as reflected in the SRIA and allow comparison with future programme review exercises.

In total, 152 projects were active in 2023 with a total budget of almost EUR 1 billion, including the projects from the 2023 call. Table 2 shows, per pillar, the distribution of the projects that are eligible for the current programme review.

Table 2: MAWP/SRIA pillars reviewed

SRIA pillar	Programme	No. of projects	Total JU funding in million EUR
Pillar 1 – Renewable H2 production	H2020	14	63.34
	HE	23	103.15
Pillar 2 – H2 storage and distribution	H2020	9	25.35
	HE	17	93.25
Pillar 3 – H2 end-uses: transport applications	H2020	23	250.20
	HE	11	103.69
Pillar 4 – H2 end-uses: clean heat and power	H2020	11	68.83
	HE	9	41.04
Pillar 5 – Cross-cutting issues	H2020	8	13.80
	HE	8	15.07
Pillar 6 – H2 valleys	H2020	2	30.00
	HE	13	151.84
Pillar 7 – Supply chain	HE	1	6.61
Pillar 8 – Strategic research challenges	HE	3	29.61
		152	**968.76**

Source: Clean Hydrogen JU.

5. REVIEW OF PROGRAMME PILLARS

5.1. PILLAR 1: RENEWABLE HYDROGEN PRODUCTION

Hydrogen production from fossil fuels must be gradually replaced with sustainable methods on a much larger scale. Renewable hydrogen, referred to as one of the 'renewable fuels of non-biological origin' in EU legislation[19], will have a significant role in the energy mix of decarbonised societies. The projects in pillar 1 contribute to making hydrogen generation from (variable) RESs competitive and enabling the scale-up of these technologies to relevant levels. Improvements in efficiency and cost reduction are required across all hydrogen generation routes.

The main technology funded under this pillar is electrolysis. Higher-TRL technologies such as AEL, PEMEL and SOEL are supported, along with newer lower-TRL technologies such as AEMEL and PCCEL. The remaining projects funded under this pillar concern alternative routes of hydrogen production, such as hydrogen production from direct solar water splitting using solar thermal heat (solar thermochemical), or from pyrolysis/gasification processes for hydrogen production from biomass/biogas.

Overview of research areas

Low-temperature electrolysis

For **alkaline electrolysis**, taking into account the whole project portfolio of the Clean Hydrogen JU, 11 projects within the hydrogen production pillar have been classified as contributing to the development of AEL technology (although some of these have worked on both AEL and PEM electrolysers).

The energy consumption per kg of hydrogen has declined sharply over the years, with most projects getting closer to the target values. However, in operation, none of the systems deployed have proven to be able to produce hydrogen at 50 kWh/kg, which was the 2020 MAWP/SRIA target. In terms of CAPEX (EUR/kW), there is a trend towards lower values with more than one project achieving the SRIA 2024 cost target. For operation and maintenance costs, the few projects reporting have costs far above the targets, with a small trend towards improvement in more recent years. As for the other targets, it is difficult to highlight trends since only a few projects have reported on their achievements. In particular, degradation is a concern since it is not clear what the status regarding the lifetime of the technology is at present.

Proton exchange membrane electrolyser technology has been investigated by 18 JU projects in total, some of them working on both PEMs and AEL. In addition, projects under other pillars, including renewable hydrogen production workstreams (e.g. hydrogen valleys or HRSs) have also contributed to this research area.

The previous programmes successfully delivered on MAWP targets as regards the performance of PEM electrolysers, although performance at system level can differ from performance at stack level. A key challenge was to upscale the PEM electrolysers to a multi-MW level. On this, much progress has already been achieved. There are, in fact, projects that are well on track to reach not only the 2024 KPIs but even certain 2030 SRIA targets. However, projects need to focus on obtaining all necessary KPIs simultaneously under the same standard boundary conditions.

19 https://energy.ec.europa.eu/topics/energy-systems-integration/hydrogen/renewable-hydrogen_en

In terms of the target for CRMs, there has been a strong decrease in the values submitted to TRUST, from an average of around 0.74 mg/W in the years 2015-2020 to around 0.16 mg/W in 2022 and 0.15 mg/W in 2023. Regarding energy consumption, if only pillar 1 projects are considered, the minimum value reported has also decreased over time from 60.5 kWh/kg H2 in 2015 to 49.8 kWh/kg H2 in 2021 (53.8 in 2022), whereas the average value in 2022 was 55.6 kWh/kg H2. The degradation rate submitted by projects since 2020 has reached an average value of around 0.25 % per 1 000 hours of operation, with a considerable decrease of this value in 2023 to about 0.13 % per 1 000 hours. Current density was reported at 3.0 A/cm2 in 2023, compared to 2.3 A/cm2 in the period 2015-2019, achieving even the 2030 SRIA target.

For **anion exchange membrane electrolysis**, no historical data are available. AEMEL is a low-TRL technology that operates in alkaline media but using a solid electrolyte. In principle, this means it can combine the use of non-platinum-group metal catalysts with the production of high-purity hydrogen due to the presence of the solid electrolyte. Of the 7 projects investigating AEMEL technology, 3 projects (CHANNEL, ANIONE and NEWELY) were funded under the 2019 call and the reported KPIs were estimated from single-cell tests only, with promising results against the SRIA 2024 targets. Four more projects in the same research area started in 2023-24.

In terms of progress towards achieving the JU KPIs:

- the energy consumption reported by the best project has achieved the SRIA 2024 target, and the average estimated value (51.9 kWh/kg) is 2 % below the 2024 SRIA target;
- for current density, the target appears to have been set too low, as one project reported having achieved 1 A/cm^2, thus meeting the SRIA 2030 target;
- efforts to reduce PGM loading in catalysts are still being pursued and it seems that, as expected, catalysts with lower PGM loading do not achieve best performance.

High-temperature electrolysis

Solid oxide electrolyser technology has been developed by 14 JU projects so far. The previous programmes have delivered well on most of the targets set in the revised 2018 MAWP. SOEL technology is less advanced than AEL or PEMEL, with fewer projects at higher TRL levels. Therefore, most of these KPIs have been achieved by only one or two projects (except for production loss, where several projects achieved the 2020 target).

Regarding system energy consumption, the reported values in 2023 either are very close to or meet the SRIA 2024 target of 39 kWh/kg H2. For the system CAPEX KPI, the 2020 SoA has been reduced to EUR 3 550 per (kg/d) in the SRIA from the MAWP SoA value of EUR 12 000 per (kg/d) for 2017, but the SRIA 2024 target of EUR 2 000 per (kg/d) has not been achieved yet. Finally, the SRIA 2024 target for reversible capacity of 30 % has been achieved, with two projects reporting it at 33 %.

Proton-conducting ceramic electrolysers, although still a low-TRL technology, can be highly efficient, even compared to ion-conducting SOELs. PCCELs can operate in an intermediate temperature range (400-700 °C), which is an advantage in terms of material degradation and external heat demand.

Other routes of renewable hydrogen production

Alternative methods for hydrogen production are being investigated by four ongoing projects (historically 17 projects). The routes covered are hydrogen production by solar thermochemical water splitting, gasification of biomass and photocatalysis. The objectives of such projects seem to be more challenging than anticipated, highlighting possible fundamental bottlenecks at reactor design and operational regime level. As a result, achievements are under-reported and most targets have not been met yet, with the exception of system energy use of biogas reaching a value of 41.7 kWh/kg, exceeding the 2030 target of 57 kWh/kg.

Highlights

In LT electrolysis, there are a number of high-TRL demonstration projects validating electrolyser solutions for a range of environments and applications. These projects achieved very high visibility. In particular, demonstrations in an industrial environment or in remote areas were challenging, but overall, the projects were successful in overcoming the various hurdles such as additional safety measures, permits and harsh environments.

The three AEMEL projects were instrumental in bringing AEMEL to a higher TRL, also triggering new projects aiming for either PFAS-free membranes or lower CAPEX costs. Research projects on AEMEL show good progress when it comes to the development of components but should consider the potential for mass manufacturing and quality of stack assembly at an earlier stage in the project.

The JU is also still playing a leading role in the development of PEMEL technologies, contributing significantly to SoA improvements regarding KPIs such as efficiency.

Regarding HT electrolysis, the increase in capacity to MW scale helps to establish SOEL as a competitive option for the large-scale production of clean hydrogen from RESs, including waste heat utilisation (at system level) for higher efficiencies. Also, there is clear progress regarding the durability of SOEL, to the extent that the targets have been made more ambitious.

PCCEL has great potential for increasing the overall efficiency of hydrogen generation systems when integrated into industrial processes. The capacity of PCCEL to extract hydrogen from different gas mixtures[20] and its role in purification and compression of hydrogen, which enhances process efficiency at the system level, was emphasised mostly by the WINNER project.

Finally, Europe is developing solar hydrogen production methods.

Gap analysis – main JRC recommendations

The Clean Hydrogen JU is making a substantial effort to establish a solid basis for advancing technological performance, in particular in the areas of PEMEL and SOEL, in order to achieve the goal of the hydrogen strategy to produce hydrogen sustainably at mass scale. It is also positive that the programme is supporting PCCEL and AEMEL technologies, as these may have advantages for some applications.

The focus on areas of added value must continue, including both lower-TRL research that will develop the next generation of hydrogen generation technologies, and selected demonstrations that should focus on first-of-a-kind deployment in applications that can assist rapid embedding in industrial settings.

Industry-relevant projects, in particular, will have to make efforts in cross-sectoral dissemination and reaching out to non-expert, less technically oriented audiences in order to better explore the potential of the developed technologies in sectors that have not yet been considered or have received only little consideration. Such sectors may also have emission reduction potential and energy transition needs. In this respect, interaction with IPCEI projects could be beneficial for outreach to less-expert audiences.

Cooperation with other initiatives' projects (Connect Europe Facility, Innovation Fund) and IPCEI projects could be beneficial for achieving joint collaborations (design requirements, testing protocols, material use and sourcing, prototype testing, etc.) and dissemination, particularly to value chain actors and stakeholders. Dissemination to regulatory fora and standardisation bodies should include the applicability of the developed test methodologies to certification, safety, energy performance and quality assurance requirements.

As water-related issues attract more attention from policymakers, an assessment of the water requirements (quantity and quality) of newly developed system designs or new materials may bring valuable insights. In addition, new materials allowing the electrolysis of lower-quality water may reduce the energy consumption needs

20 The SINGLE project (see pillar 2) also uses PCCEL technology to extract hydrogen from ammonia.

of water treatment systems and improve the overall energy efficiency of electrolysis systems. As mentioned in the SRIA, the focus on new technologies for direct seawater electrolysis could become increasingly important for the future.

LT electrolysis: The projects are making clear efforts to define a common approach through the standardisation and harmonisation of testing protocols: standardisation of components and accessible interfaces should receive a high and increasing level of attention, with the aim of increasing production rates to reduce the cost of electrolyser plants. However, at higher manufacturing rates, the share of the total cost of the stack will be lower; the BoP components are thus becoming more relevant. Modules of greater but standard sizes are also relevant to reduce costs. Also, an investigation into the interest in and potential of electrolysis of non-conventional sources of water (such as public, industrial or mining wastewater) could be of interest. KPIs, which are currently mostly designed for steady-state operation, should not only be defined together (there are KPIs that are highly correlated, such as current density and degradation, efficiency and CRM usage) but should also assess the response of the systems in dynamic operation modes.

HT electrolysis: There is still considerable room for improvement on both technical and, in particular, economic KPIs associated with the technology. Additional efforts to lower the operating temperature and increase the output pressure of the hydrogen produced should be made. Also, the potential dependence on rare earth metals (some of which are considered as CRMs by the European Commission) should be considered, both in economic and ecological terms, when electrolysers are deployed at greater scale. Recycling options should be investigated, together with restricted use of CRMs.

HT electrolysis systems should be integrated into industrial processes to increase overall energy efficiency at plant level, thus generating benefits from an increased focus on heat utilisation and process integration.

Alternative methods of hydrogen production: There are still great challenges at material and component levels, including at reactor design and operational regime level. A new study, comparing the various alternative hydrogen production methods in terms of cost and environmental impacts, could be launched (an update of the study funded by the FCH JU in 2015) to identify the different pathways and assess the current TRLs carefully.

5.2. PILLAR 2: HYDROGEN STORAGE AND DISTRIBUTION

The REPowerEU plan and the European hydrogen strategy recognise the important role that hydrogen storage and distribution have in further supporting the penetration of renewable hydrogen in Europe. The plan envisions the import of 10 million tonnes of hydrogen by 2030, on top of the 10 million tonnes that will be produced in Europe. In the same context, the hydrogen strategy also mentions that logistical infrastructure must be developed in order to transport hydrogen from areas with large renewable potential to demand centres across Europe.

There are various options for transporting and storing hydrogen, and the SRIA calls for a pluralistic approach with respect to the technologies to be investigated and supported. These technologies can then serve as building blocks for an EU-wide logistical infrastructure in its multifaceted complexity.

Overview of research areas

Aboveground storage: Hydrogen can be stored as compressed gas in aboveground pipelines or other types of pressure vessels. Since the mid-1960s, the two largest liquefied hydrogen storage tanks (around 212 tonnes of liquefied hydrogen each) have been operating at NASA facilities. Metal or chemical hydrides allow hydrogen storage at high volumetric and gravimetric density at low pressures. Cyclability, a suitable heat supply and thermal management have proven to be particularly challenging for this storage option.

This research area currently consists of one finished project, HYCARE, focusing on solid-state storage. The HYCARE project targeted the upscaling of a solid-state hydrogen storage system based on metal hydrides and therefore addressed the KPI on storage size, albeit at much smaller scale (estimated 46 kg H_2 reversibly stored) than the SRIA target of 5 tonnes for 2024. The CAPEX of the system is also more than 17 times that of the SRIA target for 2024. The system is not optimal for large-scale storage of hydrogen and should not go much below a CAPEX of EUR 8 000/kg H_2 when storing tonnes of hydrogen.

Underground hydrogen storage: NG has been stored underground in geological formations for over a century. The most commonly used formations for underground storage of gas or other products are salt caverns, rock caverns, depleted gas fields and aquifers. The EU has about 1 160 terawatt hours (TWh) of working NG storage capacity, of which 15 % is in salt caverns. Of the diverse underground storage options, salt caverns are deemed the most promising for storing hydrogen in substantial amounts. Their inactive cavern material and absence of microbial activity make them less prone to hydrogen depletion and contamination. At present, a few instances of commercial-scale hydrogen storage in salt caverns exist in the US and the UK.

Underground gas storage facilities in porous media utilise a geological formation that is covered by an impermeable layer, creating a storage space. These formations can be depleted gas fields or aquifers. The porous geological layer is typically found at a depth of between 500 and 2 000 meters. A formation suitable for hydrogen storage should possess good porosity, high permeability and, ideally, formation pressure (to minimise the amount of cushion gas required). Porous formations offer significantly larger storage capacities than salt caverns and have a higher geographical availability. Storing NG in depleted oil or gas fields is a widely used method due to its cost-effectiveness for storing large quantities of gas. Since these fields have already been exploited, their geological characteristics are well established, which is advantageous for their potential conversion to store hydrogen. Additionally, the existing extraction and distribution equipment can be repurposed. Aquifers can also be utilised for gas storage if the sedimentary layer containing water is covered by an impermeable cap rock layer. However, compared to depleted gas fields, aquifers require more cushion gas and offer less flexibility in injecting and withdrawing gas.

Two new projects have been launched in 2024, following the path of the previous four projects already finished in 2023 or early 2024. The two projects will advance the state-of-the-art and will demonstrate large scale underground storage in salt caverns as well as depleted gas fields, but research is still necessary at a more fundamental level.

Hydrogen in the natural gas grid: Injecting hydrogen into the NG grid, together with repurposing NG pipelines for 100 % hydrogen transmission and distribution, can decarbonise the NG grids and distribute large quantities of hydrogen. Research continues in order to ensure safety, as there are remaining questions about hydrogen embrittlement and compatibility of components with hydrogen, in particular for newer high-strength steel grades (X70 or higher). Hydrogen damage can contribute to the likelihood of a loss of containment in a hydrogen pipeline due to the effects of embrittlement, reduced fracture toughness and accelerated fatigue crack propagation. Fatigue crack growth can be expected from a fluctuating load, which primarily arises from pressure fluctuations in pipelines. However, this approach may not be directly applicable to other materials like non-steel metals and plastics, which are used in low-pressure distribution pipelines.

Therefore, the scope of work covered by the two projects in this research area – HIGGS on high-pressure pipelines and CANDHY on low-pressure pipelines – is highly relevant for answering some of the open questions, as the projects will conduct tests on a large range of materials. PilgrHYm will also support efforts towards the creation of a European standard for transporting gaseous hydrogen through existing NG pipelines.

Another safety-relevant issue is hydrogen leaks; detection of hydrogen is key for preventing incidents. Although existing sensing principles for detecting combustible or reducing gases are generally applicable to hydrogen, there may be cross-sensitivity issues with other gases. Selective hydrogen sensors, which utilise the unique interactions (catalytic reactivity and solubility) of hydrogen with elements like palladium and platinum, help mitigate this problem. The sensors can detect hydrogen concentrations by measuring either the reaction heat, exchanged charge carriers or changes in the sensing material's properties (resistance, volume expansion, etc.)[21]. Fibre optic sensors have attractive properties, such as offering the possibility of remote and distributed sensing. In addition, they have intrinsic safety, as they operate with optical signals, which pose no risk of sparks or ignition. The fibres must be coated with an appropriate sensing material, most commonly palladium or tungsten based.

21 https://www.sciencedirect.com/science/article/pii/S0925400511003674

When the hydrogen concentration around a sensitive thin film is altered, the physicochemical properties of the film change, causing variations in the optical signal transmitted through optical fibres as regards factors such as intensity, wavelength and phase. By monitoring these variations, the hydrogen concentration can be determined. In the case of this research area, the OPTHYCS project will develop optical sensors and perform tests for several use cases.

There are no KPIs for this research area, only for newly built hydrogen pipelines. Two projects are funded under this research area and are complemented by actions described in pillar 5.

Liquid hydrogen carriers: Hydrogen delivery at large scale and over long distances is deemed challenging, due to the intrinsic low volumetric energy density of gaseous hydrogen. Significant investments are needed for hydrogen delivery infrastructure. REPowerEU[22] estimates these to be in the range of EUR 28-38 billion for pipelines and EUR 6-11 billion for storage.

Research is being conducted to determine the most efficient, the safest and the most sustainable method for transporting hydrogen. Over distances > 3 000 km, pipelines seem to be a less economic option than shipping of compressed or liquid hydrogen, or shipping of chemical carriers. Liquid hydrogen, due to its high gravimetric and volumetric density is a promising option for hydrogen transport, but there are still numerous technical challenges to be overcome, such as reducing the energy demand for liquefaction and boil-off management.

The main chemical carriers being considered by stakeholders are ammonia, methanol, LOHCs and synthetic NG. Ammonia production (with fossil fuels) and transport can be considered an established technology, but there is not much experience yet with its cracking (hydrogen release) at scale. Unlike methanol and synthetic NG, ammonia and LOHCs do not release CO_2 during hydrogen release. LOHCs and synthetic NG have the advantage that existing infrastructure, such as oil and LNG tankers, respectively, can be reused.

The Clean Hydrogen JU provides technical targets for chemical carriers in the SRIA for delivery cost and energy consumption. By 2024, the energy demand for liquefaction should be reduced to 8-10 kWh/kg H_2 (from 10-12 kWh/kg H_2 in the current SoA), and hydrogen carrier specific energy consumption should be 17 kWh/kg H_2, compared to 20 kWh/kg H_2 which was the state of the art in 2020. As this energy demand is one of the main cost drivers and will also determine much of the environmental impact associated with transport of hydrogen, these are crucial technological issues. Three LOHC projects are funded under this research area (HYSTOC, SHERLOHCK and UnLOHCked). Although SHERLOHCK and UnLOHCked are making progress in reducing the energy consumption of releasing hydrogen from the carrier (KPI 4 in Table 11 of the SRIA), the projects have not yet reported the energy consumption achieved.

Cracking of ammonia is a well-established technology for small-scale local hydrogen production. The suitability of such technology for scale-up to a level able to support imports of large amounts of hydrogen is however not proven. The two projects considered this year, ANDREAH and SINGLE, are developing innovative solutions for ammonia cracking and purification and aim at scaling up their TRL from 3 to 5. The scalability, in terms of feedstock processing of the ammonia cracking options, pursued by the project is not yet fully demonstrated.

The HYLICAL project is addressing hydrogen liquefaction. Conventional liquefaction through compression-expansion cycles has a high energy demand of 12-15 kWh/kg H_2[23]. Although the energy demand can be significantly reduced through upscaling and improved plant design (see also the outcomes of the IDEALHY project[24], other liquefaction routes are being investigated. Magneto-caloric refrigeration, which utilises cyclic magnetisation of tailored materials in high magnetic fields, could potentially minimise the energy requirement for hydrogen liquefaction. While magnetic refrigeration could outperform more conventional liquefaction methods, there is an absence of materials with a high magnetic entropy change across the wide temperature range necessary for hydrogen liquefaction[25].

22 https://eur-lex.europa.eu/resource.html?uri=cellar:fc930f14-d7ae-11ec-a95f-01aa75ed71a1.0001.02/DOC_1&format=PDF

23 https://pubs.rsc.org/en/content/articlehtml/2022/ee/d2ee00099g

24 https://www.idealhy.eu/

25 https://www.nature.com/articles/s41467-022-29340-2

Compression, purification and metering solutions: Compressors are needed for the delivery of hydrogen, with pressures above 700 bar required for refuelling and up to 100 bar for injection into pipelines. As compressors are the components most prone to failure at HRSs, research is needed to increase reliability, as well as to lower cost and improve efficiency. Work is ongoing in the COSMHYC DEMO project, which builds on the recently ended COSMHYC XL and its predecessor COSMHYC (see the following section on HRSs).

Hydrogen purity demands for the different end-uses vary, with low-temperature PEM FCs requiring hydrogen conforming to the stringent ISO 14687 standard (99.97 %). Depending on the source of hydrogen, there may be the need to either separate the hydrogen from a gas mixture, or to further purify the hydrogen. The term 'separation' can be used for a process to increase the concentration of hydrogen, and the term 'purification' for a step to upgrade the hydrogen quality to the desired degree. One of the objectives is the separation of hydrogen from hydrogen and NG blends with low hydrogen content (up to 20 %).

Separation and purification of hydrogen can be carried out through PSA, membrane separation, cryogenic separation/partial condensation, electrochemical separation or hybrid solutions. This process can produce purities of up to 99.999 % hydrogen, but this may entail low hydrogen recovery rates (up to 65-90 %) depending on the feed pressure. Diffusion-based techniques utilising membranes (polymer, ceramic, carbon or metal) offer lower energy demand and higher recovery rates (up to 99 %) but are currently more suited to smaller-scale installations. Electrochemical compression technology allows simultaneous separation and purification of hydrogen gas present in a (mixed) gas stream with potentially low energy demand. A more novel approach is based on proton conducting ceramic membranes based on rare earth-doped ceria oxides. These membranes exhibit protonic conductivity at high temperatures between 700°C and 1 000°C and low hydrogen permeability.

Hydrogen refuelling stations: The deployment of HRSs is expanding globally. In 2023, 85 new HRSs went into operation worldwide. The EHO reported a total of 187 HRSs at the end of May 2024. Of the 187 HRSs, 170 offer operation at 70 megapascals (MPa) for the refuelling of FC passenger cars, 59 are able to operate at 35 MPa for the refuelling of FC passenger cars and 70 offer 35 MPa refuelling for FC buses[26]. The Clean Hydrogen JU has funded the installation of 113 HRSs to date (planned, deployed and decommissioned units), including car, bus and MHV demonstration projects. The technological progress on HRSs reported here has been made by car and bus demonstration projects, which are reviewed under pillar 3.

The geographical coverage of hydrogen refuelling infrastructure continues to expand, supporting the increasing number of FCEVs deployed. Despite the continuous expansion of the geographical coverage of hydrogen refuelling infrastructure, the majority of the refuelling stations are in Germany, followed by France, the Netherlands (tied with the UK) and Switzerland. The EU HRS availability system, an initiative funded by the Clean Hydrogen JU, offers a portal providing live-status information on most public HRSs in Europe[27].

Highlights

The Clean Hydrogen JU is putting efforts into improving and advancing innovative technological solutions for solid-state hydrogen storage at an unprecedented scale. The hydrogen storage solution developed by the HYCARE project has well-defined advantages over other hydrogen storage solutions for relatively small-scale applications and certain use cases due to its lower footprint and reduced electricity consumption.

The demonstration of a salt cavern has the clear goal of validating renewable-based hydrogen value chains. Preparatory work for a salt cavern demo working with renewable hydrogen seems to be on track and valuable expertise has been gained.

Synergies are present at programme level between the HIGGS and CANDHY projects and other projects related to admixture in pillar 5, such as THYGA, SHIMMER and THOTH2. This will support regulatory and standardisation progress in this area. Also, useful results have come from the experimental campaign on the potential issues of injecting hydrogen into the gas grid, with no critical gas losses, embrittlement or other kind of damage found.

26 https://observatory.clean-hydrogen.europa.eu/tools-reports/datasets

27 https://h2-map.eu/

For LOHCs, good progress has been made by the HYSTOC project in terms of demonstrating the concept, and SHERLOHCK and UnLOHCked are working on improving the technology at a more fundamental level. Also, innovative solutions for liquid hydrogen storage and liquefaction are being developed for the first time.

COSMHYC DEMO is likely to bring metal hydride compression technology up to TRL 7. Also, WINNER paves the way for the development of innovative and low-carbon technology to extract hydrogen from gas streams through the use of proton-conducting ceramics, showing promising results in the development of tubular PCCs to be used for the ammonia cracking and reverse electrolysis process.

HRS operators with experience of operating multiple HRSs for several years have observed improvements in the availability of new stations (compared to previous station models from the same supplier), suggesting that design and operational improvements are being implemented as a result of the experiences of early stations. Best practices should be shared to ensure that HRSs from new suppliers and operators also have high availability[28].

Synergies across several projects in the programme have been observed. RHeaDHy builds on a previously funded project (PRHYDE). H2REF-DEMO builds on the H2020-funded H2REF, which was finalised in 2019. COSMHYC DEMO and COSMHYC XL are part of the same cluster of projects which build on each other (plus COSMHYC, which ran from 2017 to 2021) and have created synergies with other European projects including HECTOR and SWITCH.

Gap analysis – main JRC recommendations

Aboveground storage: The SRIA target of 5 tonnes of hydrogen stored should be revised, despite the good progress made. Actual viable business cases and market opportunities for solid state-based hydrogen storage materials should be defined, building on the analysis performed by HYCARE.

Underground storage: A clear link of all three existing projects to future hydrogen valleys should be established in order to ensure better utilisation of available caverns/gas field resources. The developed databases with a ranking of sites should be further publicised, as they can be very useful for future valleys or other large demonstration/ flagship projects. The regulatory work produced by the three projects could be considered as the basis for useful lessons learned.

A study to determine the amount of large-scale storage that will be needed in the EU in the future, in particular with regard to hydrogen imports, should analyse the interactions between port infrastructure, hydrogen imports and underground storage sites. It should be clearly identified which lessons learned are of general interest for developing future storage sites across Europe and which are site-specific. Attention should be paid to developing a template for business cases which is not site-specific and can be easily adapted to different locations.

Hydrogen in the NG grid: Given the potential climate effect of hydrogen leakage, precise figures on the potential amount of hydrogen leaked from pipelines are needed (even if the amount is small).

Also, experimental campaigns on aged pipelines are needed to understand potential issues with repurposing existing pipelines.

A stronger focus on 100 % hydrogen testing should be pursued since it appears that pure hydrogen transport will have a higher strategic value for the programme.

There is also the need to develop a pipeline integrated management system for hydrogen transmission lines. This is a complex set of inspection measures and preventive maintenance procedures aimed at guaranteeing safety and reliability, preventing incidents and maintaining the operation licence. This management system is based on knowledge of all possible degradation/failure scenarios of the whole system. It must consider material science and component behaviour.

28 https://h2me.eu/wp-content/uploads/2023/01/H2ME2-D7.19-Public-FV-Emerging-conclusions-document-%E2%80%A6.pdf

Liquid H_2 carriers and hydrogen transport: Costs and energy consumption are the key parameters in this research area. Reaction rate and cyclability remain substantial challenges, together with the improvement of the overall energy efficiency of the process. It needs to be proven whether the pursued technological solutions can be scaled up to megatonne (Mt) range. The EU needs to catch up, as Japan seems to have moved at least one advanced, long-distance LOHC delivery chain to a higher TRL. If ammonia is used as a hydrogen carrier, it will also be necessary to consider designs able to process higher quantities of feedstock.

Magneto-caloric liquefaction is still at a low TRL, and it could be useful to fund further research into more established liquefaction technologies. Also, additional focus on the safety risks and social implications of using different carriers is needed. The prevalence of actions targeting the dimension of safety and (pre)-standardisation has increased in pillar 5, and this should be followed up by actual demo projects.

Road transport of liquid hydrogen is currently not covered by any projects or call topics, except for from a safety perspective (pillar 5, PRESLHY, AWP 2022 call topic). This is a concern, and it is important for the Clean Hydrogen JU to prioritise this topic in future calls.

Compression, purification and metering: As proton conducting ceramics remain a rather low-TRL technology, a better tool to assess and track the potential techno-economic gains provided by this technology should be developed if it is to enter the market and compete with more mature technologies. Among the three processes considered in the WINNER project, the use of proton conducting ceramic electrolytes for the extraction of hydrogen from ethane appears to be the most challenging application and may require more resources for investigation than initially planned.

Hydrogen refuelling stations: Metal hydride compression is a pioneer technology dependent on hydride material performance, not only at the beginning of its life but also in the long term. Operational experience will reveal the potential of metal hydrides to withstand the necessary high number cycles. The outcomes of the COSMHYC projects should be assessed.

Also, the financial viability of HRSs might be affected by the currently low average hydrogen demand. In addition, availability tends to improve as the total volume of dispensed hydrogen increases, and issues arising during the 'teething period' have been addressed. The lessons learned from the various HRSs operating at present should be analysed to identify and further define the main causes of failure. Car HRSs seem to have more problems than bus HRSs in terms of availability (see pillar 3). Management of components that are either unreliable (compressors, chillers and dispensers) or prone to damage (including damage caused by mishandling by users) is necessary to shorten downtimes, and further development of the supply chain is needed to produce more reliable and robust items.

Further analysis of hydrogen chillers causing downtime in HRSs must be performed. As larger flows of hydrogen are dispensed for truck fuelling operations, funding a project on developing innovative and efficient cooling for dispensed hydrogen should be considered.

5.3. PILLAR 3: HYDROGEN END-USES: TRANSPORT APPLICATIONS

Pillar 3 aims to advance the penetration of hydrogen and FC technologies in the transport sector. The predecessor of the Clean Hydrogen JU, the FCH JU, dedicated significant efforts to developing, validating and demonstrating technologies for FC MHVs, FC buses and FCEV passenger cars. These technologies are now considered ready for market deployment. Still, solutions in sectors such as HDVs, off-road and industrial vehicles, trains, shipping and aviation need further development and demonstration. Such solutions are based on the transfer of technical knowledge already gained in FCEVs and FCEBs, while cost reductions and higher efficiencies can be achieved by scaling and process integration.

A number of technology routes require further advancement, especially in the context of reducing costs and increasing durability, in order to make them competitive with incumbent technologies. These include:

- improving the main technology building blocks that can be applied across a range of different transport applications, amongst which are FC stacks and hydrogen tanks;
- adapting FC systems from other vehicles (urban buses/cars) for long-distance coaches and HDVs;
- producing components for rail freight and shunting locomotive applications;
- adapting FC components to waterborne transport and developing next generations based on findings from first demonstrations;
- developing tanks and FC technologies specifically adapted for aviation, focusing in particular on liquid hydrogen technologies.

Overview of research areas

Heavy-duty vehicles (building blocks) – FC stack and FC system technology: Although commercial PEMFC systems for transport and stationary applications with satisfactory performance are currently available, their durability still needs further improvement. Loss of performance of FC systems is still a bottleneck in wide dissemination of hydrogen FCs in industry and transport. There is still development needed regarding the understanding of degradation mechanisms, their causes and mitigation strategies to improve PEMFC durability.

Another difficulty constraining broad adoption of PEMFC technology is usage of rare and expensive materials, most importantly PGMs. Current SoA catalysts with PGM loading > 0.4 mg/cm^2 can provide reliable performance and satisfactory durability[29]. However, while low-PGM-loading catalysts can provide particularly reliable performance at the beginning of life, degradation rates for low PGM and PGM-free loading materials are still unsatisfactory as demonstrated by CRESCENDO and PEGASUS.

Heavy-duty vehicles (building blocks) – on-board vehicle hydrogen storage: On-board vehicle compressed hydrogen storage technology is already well established. Progress was made in the technology thanks to several FCH JU-supported projects (HYPERCOMP, HYPACTOR, FIRECOMP) focusing on safe-by-design, carbon fibre-reinforced vessels with optimised composite wrapping. SoA compressed hydrogen storage systems are made up of carbon fibre composite-reinforced vessels. A key question is how to cut tank costs by reducing the amount of carbon fibre used while maintaining storage performance and safety levels. The COPERNIC, TAHYA and THOR projects developed a complete compressed hydrogen storage system.

An important example of technological progress is the development of conformable tanks, which will allow optimisation of the volume of hydrogen stored by adapting the tank shapes to the available free space in the vehicle.

Heavy-duty vehicles: FCETs are considered one of the best options for decarbonising heavy-duty road freight transport. FCETs are potentially best suited for longer-range missions and the heaviest goods, enabling connectivity with more remote areas than other solutions such as battery or catenary trucks[30]. Manufacturers are working on different concepts of hydrogen truck, for instance Hyundai Xcient[31], Toyota/Hino[32], Hyzon Hymax[33], Volvo[34], Nikola[35], Iveco[36] and Daimler GenH2[37].

29 Cullen, D.A., et al., 'New roads and challenges for fuel cells in heavy-duty transportation, *Nature Energy*, 2021: (https://doi.org/10.1038/s41560-021-00775-z).

30 Decarbonisation of heavy-duty transport: zero-emissions heavy goods vehicles, JRC, 2021 (https://publications.jrc.ec.europa.eu/repository/handle/JRC125149)

31 https://trucknbus.hyundai.com/global/en/products/truck/xcient-fuel-cell

32 https://global.toyota/en/newsroom/corporate/32024083.html

33 https://www.hyzonmotors.com/vehicles/hyzon-hymax-series

34 https://www.volvogroup.com/en/news-and-media/news/2022/jun/news-4293110.html

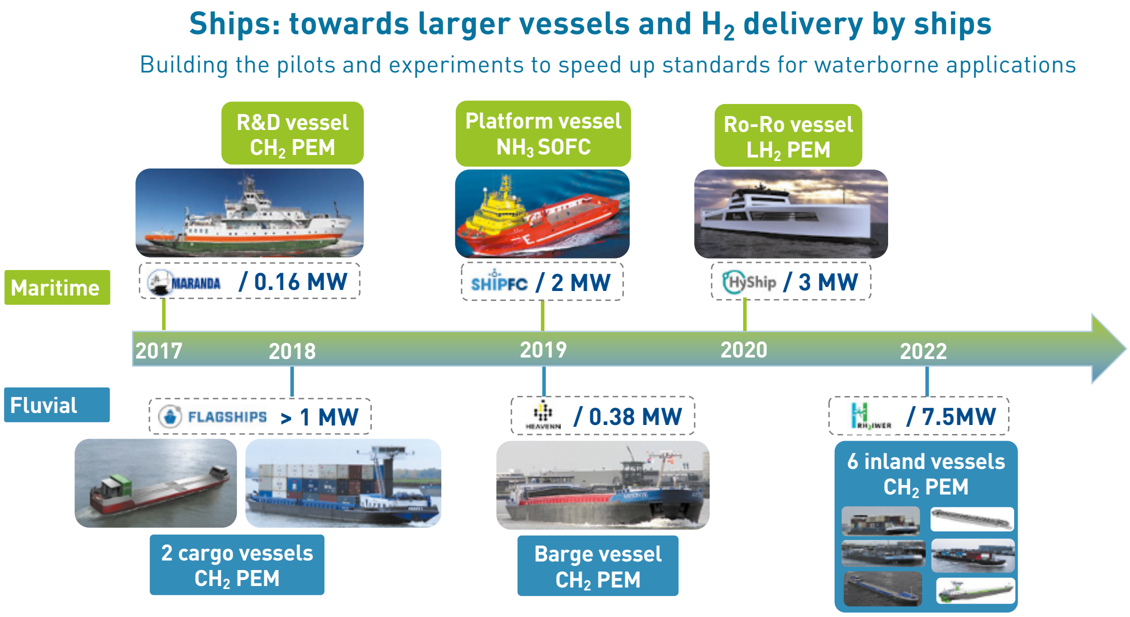
35 http://nikolamotor.com/

36 https://www.iveco.com/global/Press/PressReleases/2023/IVECO-to-produce-and-market-its-Heavy-Duty-Battery-Electric-Vehicle-and-Heavy-Duty-Fuel-Cell-Electric-Vehicle

37 https://media.daimlertruck.com/marsMediaSite/en/instance/ko/GenH2-Truck.xhtml?oid=47469461

Waterborne applications: Since 2017, the Clean Hydrogen JU has been funding several projects demonstrating FC-powered vessels as shown in Figure 6. The MARANDA project finished in 2022, while the most recent project, RH2IWER, started in 2023 and will demonstrate six inland waterway cargo, tanker and bulk vessels.

Figure 6: Clean Hydrogen JU projects on maritime



Source: Clean Hydrogen JU.

Rail applications: Hydrogen and FC technology for rail applications has been trialled across Europe, Asia, North America, the Middle East, Africa and the Caribbean since 2005[38]. Although those trials show that FC and hydrogen technology can meet the requirements for rail applications, there are few demonstration projects of hydrogen train prototypes. FCH2RAIL is the only project in the rail applications research area. It demonstrates a hybrid powered catenary and fuel cell train[39].

Aeronautic applications: Starting from HYCARUS's experience[40] and following up on the Clean Hydrogen JU project, FLHYSAFE, which aims to design and demonstrate the feasibility of using a PEMFC system as an emergency power unit, new projects have started: BRAVA – Breakthrough Fuel Cell Technologies for Aviation[41] (started 12.2022) and NIMPHEA – Next Generation of Improved High-Temperature Membrane Electrode Assembly for Aviation (started 1.2023)[42]. In March 2023, the Clean Aviation and Clean Hydrogen JUs signed a memorandum of understanding[43] to enable synergies between the two JUs based on strategic and programmatic alignment, firstly through a joint technical roadmap and secondly through alignment of project implementation.

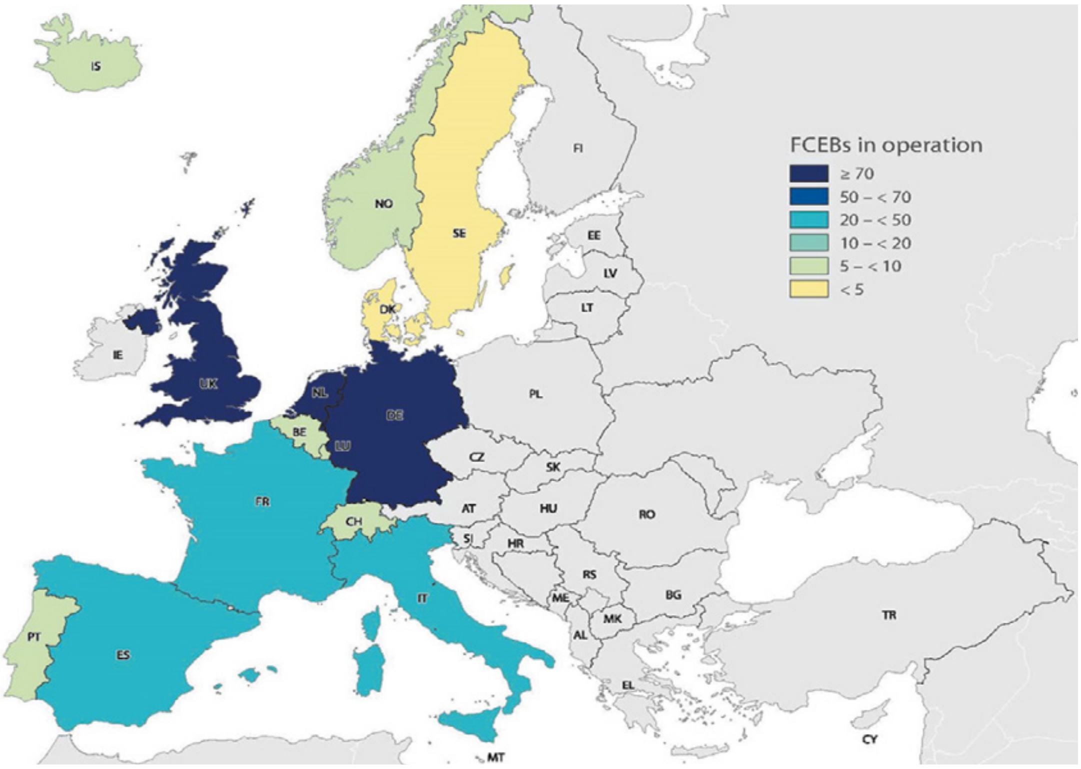
Buses and cars: The technical specifications for buses (FC power capability, storage capacity, range, and hydrogen consumption) have clearly improved worldwide over the last few years. After China, European countries have the largest number of FC bus manufacturers, an indicator of technological progress and innovation[44]. This is partly due to the significant contribution of Clean Hydrogen JU demo projects (CHIC, HIGH V.LO-CITY,

38 Study on the use of fuel cells and hydrogen in the railway environment, FCH 2 JU, 2019.
39 https://verkehrsforschung.dlr.de/en/projects/fch2rail
40 https://cordis.europa.eu/project/id/325342/en
41 https://www.clean-hydrogen.europa.eu/projects-repository/brava_en
42 https://www.clean-hydrogen.europa.eu/projects-repository/nimphea_en
43 https://www.clean-hydrogen.europa.eu/media/news/clean-aviation-joint-undertaking-and-clean-hydrogen-joint-undertaking-strengthen-cooperation-2023-03-23_en
44 https://fuelcellbuses.eu/suppliers#29

HYTRANSIT, 3EMOTION, JIVE and JIVE 2) focusing on the large-scale demonstration of FC buses in Europe since 2010. Additionally, these bus demos have improved public acceptance of FC buses in Europe.

A major contribution of the Clean Hydrogen JU projects is the large-scale deployment of FC buses in Europe. Figure 7 shows the total European FCEB fleet deployed from 2005 to 2023, including data from CUTE, HYFLEET:CUTE, CHIC, HIGH V.LO-CITY, HYTRANSIT, 3EMOTION, JIVE and JIVE 2. The number of FCEBs deployed during this period surpassed the 400-unit milestone. The success of bus demo projects is demonstrated by the fact that in various cities, bus operators joined the projects after they had started. This is evidence of a growing involvement of regions and a steady increase in private contributions to the financing of the demo projects.

Figure 7: FCEBs deployed in Europe from 2005 to 2023



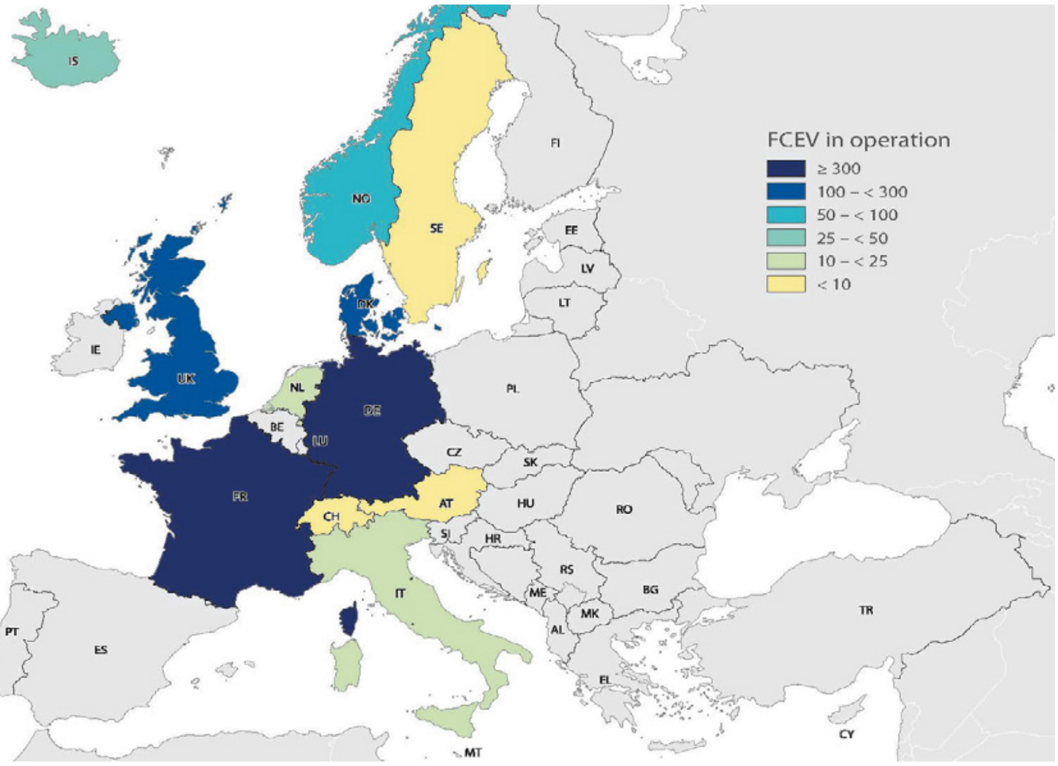
Source: JRC based on TRUST data from Clean Hydrogen JU, 2024.

The achievements of these demonstrations over the years and their implications for the wider roll-out of hydrogen mobility across the EU are discussed in a new technical report authored by the JRC and the Clean Hydrogen JU[45].

Similarly to FC buses, the Clean Hydrogen JU has also been supporting FC vehicle projects (H2MOVES SCANDINAVIA, HYTEC, SWARM, HYFIVE, H2ME, H2ME2 and ZEFER) since 2010. Clean Hydrogen JU projects under H2020 (H2ME, H2ME2 and ZEFER) focused on accelerating the market penetration of FC vehicles deployed in Europe, demonstrating market readiness and identifying business cases, as well as developing the necessary refuelling infrastructure at a competitive cost. A major contribution of the Clean Hydrogen JU projects is the large-scale deployment of FC cars in Europe. Figure 8 illustrates the total FCEV fleet rolled out across Europe from 2010 to 2023, encompassing data from the H2MOVES SCANDINAVIA, HYTEC, SWARM, HYFIVE, H2ME, H2ME2 and ZEFER projects. The total number of FCEVs deployed during this time passed the 1 300-unit benchmark. These projects have laid the foundation for the first genuinely pan-European network and aided in the establishment of the world's most extensive HRS network.

45 https://publications.jrc.ec.europa.eu/repository/handle/JRC137101

Figure 8: **FCEV deployed in Europe from 2010 to 2023**

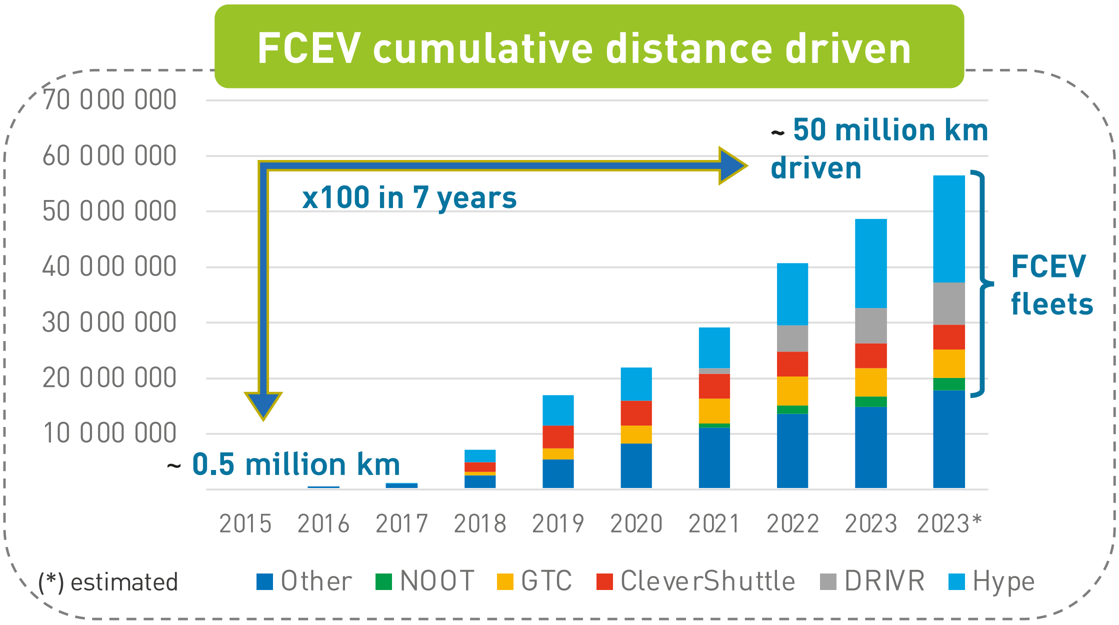


Source: JRC based on TRUST data from Clean Hydrogen JU, 2024.

Positive business cases have been demonstrated by the H2ME2 and ZEFER projects. FCEVs showed an operational advantage against other zero-emission mobility solutions in terms of high mileage and high required availability applications, such as taxi fleets. Comprehensive lessons have been learned on customer acceptance, the business case for FC vehicles and the technical performance of HRSs and FC vehicles under high utilisation.

Based on data collected in TRUST on the performance of the 674 FCEVs operating in 2023, the deployed FCEVs drove over 10 million km with a reported consumption of 93.6 tonnes of hydrogen. This continues the upward trend over the years, showing an increase from 2022, when 472 FCEVs drove 8 million km with a consumption of 91.7 tonnes of hydrogen. As shown in Figure 9, Clean Hydrogen JU-funded vehicles have driven a total of almost 49.5 million km and consumed almost 742 tonnes of hydrogen since 2016, avoiding the emission of about 2 145 tonnes of CO_2.

Figure 9: FCEV cumulative distance driven from 2015 to 2023



Source: Clean Hydrogen JU.

The total number of Clean Hydrogen JU-funded HRSs is 113[46] including car, bus and MHV demo projects (planned, deployed and discontinued units). Demonstration projects are recurrently suffering from the lack of experience of local authorities and the absence of standardised processes for reviewing and approving HRS permit authorisations. However, lead time for commissioning an HRS is decreasing (e.g. in Germany to 12 months from 24 previously). The Clean Hydrogen JU-funded multi-fuel HRS project, MultHyFuel is contributing to easing HRS permitting issues.

Highlights

Building blocks

The use of non-PGMs for electro-catalysis has been studied in the projects with encouraging results and provides the basis to potentially reduce the use of EU-defined CRMs. Also, several projects (i.e. IMMORTAL, DOLPHIN, MORELIFE, FURTHER-FC, RealHyFC and others) are developing knowledge including testing protocols and tools to improve FC design and adapt FC features to fit the requirements of automotive applications, both light and heavy duty.

At present there are different alternatives for the placement of hydrogen storage on-board HDVs. One is to store the hydrogen in vertical vessels installed behind the cabin. Another is having several vessels interconnected by long pipelines or using conformable tanks. There is insufficient information on the behaviour of the storage system configuration during refuelling.

Heavy-duty vehicles

HDV/truck projects will, as has been the case for the bus demos, help to establish an EU supply chain for FCs and FC systems suited for heavy-duty applications. Likewise, truck projects can provide valuable feedback to compressed hydrogen storage tank manufacturers (e. g. storage requirements and sizes, locations for tanks and configuration of the system, number of fills, activation of temperature and pressure release devices, etc.). Furthermore, there is a certain potential to extrapolate results coming from JIVE refuelling operations to support

46 Including two deployed and discontinued stations

future flagship projects on heavy-duty trucks, in particular as regards the handling of large quantities of hydrogen, use of large-capacity HRSs and the requirement to deliver large amounts of hydrogen on-site (800-1 000 kg/day).

Maritime applications

Clean Hydrogen JU waterborne projects are gaining visibility as the demonstration activities of H2PORTS and FLAGSHIPS are starting. Further demonstration of the use of hydrogen in inland navigation will take place in RH2IWER. The FLAGSHIPS demonstration sites have committed to continuing the operation of vessels after the project is finished, the operator and owners of the Viking Energy container ship from the SHIPFC project will continue its demonstration, and the machines in H2PORTS will remain in operation. All of this increases the impact of the JU initiatives.

Aeronautics applications

Activities on H_2-related aircraft technologies are aligned with the Clean Aviation and Clean Hydrogen joint technical roadmap and the respective SRIAs of the two JUs.

Most importantly, on 7 September 2023, the HEAVEN project consortium successfully completed the world's first piloted flight of an electric aircraft powered by liquid hydrogen. The aircraft took off from Maribor airport, Slovenia. Of the four test flights conducted on the day, one lasted over 3 hours. The results indicate that using liquid, instead of gaseous hydrogen doubles the range of the HY4 aircraft from 750 km to 1 500 km. This is a critical step towards development of emission-free, medium- and long-haul commercial flights.

Bus and car demonstration

Technological advancements in the BEV sector and the increase in the number of models available to customers in Europe means that BEVs are likely to capture the main market shares for light-duty vehicles. FCEVs are expected to remain a necessary solution for these applications, which depend on the ability to refuel rapidly and complete high daily mileages when required. The further commercialisation of hydrogen mobility relies on scaling up demand, including demand from heavy vehicles.

The H2ME2 and ZEFER projects have demonstrated the viability and practicality of FCEVs of different sizes in meeting the needs of a range of existing vehicle users; over 3 000 light-duty hydrogen vehicles are now in operation in Europe. Several countries now have hundreds of FCEVs in operation. The largest concentrations are found in taxi and ride-sharing fleets in city centres (with over 500 FC taxis in Paris). In addition, there are an increasing number of business users and company cars used by early adopters, especially in Germany. A positive business case has been demonstrated by these projects, so deployment partners have plans to scale up their FCEV fleets. Also, following suggestions in previous assessments, demo projects are paying more attention to social acceptance and are seeking feedback from drivers and users.

The integrated solutions offered by partnerships between powertrain manufacturers, bus manufacturers and hydrogen providers are promoting the acceleration of the development of hydrogen mobility in Europe. There are already providers offering a 'package solution' including hydrogen production, storage and dispensing, along with HRS operation and maintenance.

Gap analysis – main JRC recommendations

Building blocks: Best practices to develop, test and manufacture MEAs and stacks for use in transport applications (HDVs, rail, maritime and aviation) have been demonstrated (Autostack, Autostack-Core and Autostack Industrie) and must be further disseminated.

Reduction of PGM catalyst loading is a key factor in minimising CAPEX of PEMFC stacks and reliance on CRMs. Experiments prove that nowadays low (< 0.3 mg/cm^2) and ultralow (< 0.123 mg/cm^2) PGM-loading catalysts provide similar performance to high-PGM-loading catalysts (> 0.5 mg/cm^2). However, PGM content reduction leads to severely increased degradation of catalysts, resulting in poor durability of low-loading MEAs as compared with their high-PGM-loading equivalents. Projects usually address one of these two issues: PGM content reduction or FC durability, but it is rare that both problems are investigated simultaneously. To make truly cost-effective and affordable PEMFCs, only feasible low-PGM/PGM-free electro-catalyst alternatives and their mass adoption should be given further emphasis; this should include use of appropriate screening tools based on computational materials science prior to lab-scale candidate testing.

Synergies between pilot manufacturing, materials research and fit-for-purpose testing should be better exploited to facilitate innovative FC designs that are ready for sustainable scale-up where use of CRMs is explicitly restricted, earth-abundant materials are used and harmful substance usage is avoided. Also, synergies between FC research, electrolyser research and research on other electrochemical conversion and storage technologies, as well as filtration, separation and water treatment including desalination should be actively encouraged, for example, through common topics in joint calls with other JUs and/or CINEA.

The possible ban on PFASs should receive timely and appropriate attention as regards the early and stepwise development of F-gas free MEAs suitable for deployment in future automotive settings (among other applications).

The projects on on-board hydrogen storage are truly relevant for the next phase of the Global Technical Regulation No.13[47]. The THOR and SH2APED projects should be involved in the working groups and present their findings. Also, projects tackling the development of storage systems for liquid hydrogen may help with advancing FCs and hydrogen HDVs, vessels and aircraft.

Heavy-duty vehicles: At present, homologation is granted following an individual vehicle approval process. The overall certification process for hydrogen vehicles is very detailed and is a source of delays in project execution. This should be taken up by future projects, documenting the experiences from H2HAUL, REVIVE and H2ACCELERATE TRUCKS. The requirement to obtain a registration plate (matriculation) for hydrogen trucks varies from Member State to Member State.

Maritime applications: Lack of regulations and suitable standards makes the approval of vessels and the permitting of hydrogen infrastructure in ports difficult. An open roadmap must be established urgently with the active involvement of all relevant stakeholders to close existing RCS gaps and consistently monitor implementation measures eventually taken by global standardisation and regulatory bodies in the maritime sector.

Hydrogen fuel supply and bunkering requires lengthy negotiations with supply companies; definition of specifications, safety requirements and standardisation for the compressed hydrogen supply chain in ports are necessary (FLAGSHIPS, RH2IWER and H2PORTS could contribute). Also, the liquid hydrogen supply chain is non-existent. There are few production facilities in Europe and available liquid hydrogen is already dedicated to other end-uses, making collaboration with projects in pillar 2 a necessity.

Aeronautics applications: Similarly to maritime applications, the lack of regulations and suitable standards makes the approval of aircraft and the permit of hydrogen infrastructure at airports difficult. Projects should be aware of the lengthy permitting processes for equipment approval. Also, the cryogenic supply chain is still limited.

Bus and car demonstration: The potential of FC and hydrogen coaches to contribute to decarbonisation of road passenger transport is high. A larger initiative will be beneficial for the progress of the technology as it has been for FC buses. Any such project must pay special attention to how to address the regulations affecting hydrogen systems and type approval of retrofitted vehicles and the challenge of retrofitting diesel coaches to the satisfaction of coach operators.

There is a weak supply chain of components for hydrogen mobility applications in general. The main issue is that manufacturers tend to follow demand. There is little flexibility to increase the stock of spare parts, and increases in manufacturing capacity and cost optimisation are limited.

47 https://unece.org/transport/standards/transport/vehicle-regulations-wp29/global-technical-regulations-gtrs

FC buses encounter difficulties competing against the lower costs of battery electric buses. This situation was accentuated during 2022 as the energy crisis impacted on hydrogen prices at the pump, affecting the financial viability of projects. Maintenance and operational costs for buses have become too high for some operators to commit to projects, especially due to the high hydrogen prices observed in 2022. The situation continued through 2023, although with less hydrogen price volatility.

The business case for hydrogen production from renewables and operation of refuelling stations currently faces challenges due to the scale of demand relative to the costs of installing and operating infrastructure. With a higher magnitude of demand, both stations and hydrogen production can become more cost-effective, and the development of the European supply chain will accelerate, bringing improved station reliability and economic opportunities.

5.4. PILLAR 4: HYDROGEN END-USES: CLEAN HEAT AND POWER

The overall goal of this pillar is the development of renewable and flexible heat and power generation systems for different end-users – from domestic systems to large-scale power generation plants. The widespread deployment of competitive FCH technologies can deliver substantial benefits in terms of energy efficiency, emissions and security, while simultaneously enabling the integration of renewables into energy systems.

A new research area was introduced to the programme, with six projects focusing on hydrogen, ammonia and NG combustion in gas turbine combustors and boiler burners. Turbines, boilers and burners are new elements in the SRIA and offer an opportunity for repurposing of existing infrastructure, reducing investment costs and ensuring a smooth transition to renewable gases and zero-carbon power generation. Gas turbines and burners are fuel-flexible, tolerate trace impurities and promote cost-effective and energy-efficient hydrogen conversion.

Although preferential funding is given to systems using 100 % hydrogen, hydrogen mixture solutions in the gas grid of up to 20 % are also proposed for support in the SRIA during the transition phase. Such solutions can be stationary FCs, gas turbines, boilers and burners.

Stationary fuel cell technologies

PEMFC technology: Overall, 35 projects under this pillar have contributed and continue to contribute to the development of PEMFC technology: 11 projects are addressing CHP technologies, 10 projects concern next-generation research areas, 8 projects address off-grid applications and 6 projects cover other research areas.

The projects have reached many of the targets set in the 2020 MAWP (electrical efficiency, availability and CAPEX), and SRIA 2024 targets seem to have been met in some cases. The lifetime target has been met for micro- and medium-sized FCs, and, in terms of durability, micro-FCs exceeded the target of 50 000 hours, achieving at least 80 000 hours in 2023. Also, the thermal efficiency target was met on average for micro- and medium-sized FCs. The SRIA 2024 targets are yet to be met in most of the cases.

SOFC technology: Between 2011 and 2023, 34 projects under this pillar contributed to the development of SOFC technology, and 10 projects under review are targeting this technology.

The 2020 MAWP targets have been met to a significant degree or are close to being achieved within the Clean Hydrogen JU programme. The 2020 MAWP CAPEX target has been met for all devices. The lifetime target has also been met on average by devices of all sizes. The 2020 MAWP availability and reliability targets have already been met by the micro-devices, while the durability target has been met for medium-sized devices. The 2024 SRIA targets are yet to be met in most of the cases.

Overview of research areas

m-CHP: This area includes one project – PACE – exploring the possibility of deploying both PEMFCs and SOFCs fuelled with NG for FC micro-cogeneration for small stationary applications. The project showed the potential of FC micro-cogeneration as a feasible technology allowing the production of heat and electricity for a small business or house from a single fuel. SRIA efficiency and availability targets for 2024 have been met. Moreover, for some OEMs the durability of stacks has achieved the 2030 targets set in the 2014-2020 MAWP of the FCH 2 JU.

Commercial-sized systems: This research area contains two demonstration projects focused on FC-based systems for power and heat solutions in the mid-sized power ranges of up to 60 kW, namely COMSOS and E2P2, both exploring SOFC technology. In addition, three other projects – SO-FREE and AMON using SOFC technology for commercial-sized systems and EMPOWER using HT PEMFC technology – are included in the 2024 programme review.

Industrial-sized systems: The industrial-sized CHP research area includes projects dealing with large-scale systems, usually at MW scale. Three projects are considered in the 2024 programme review, namely SWITCH, 24/7 ZEN and CLEANER.

Off-grid/back-up/gensets: This research area contains the demonstration projects focused on off-grid applications, both in remote locations and temporarily powered event areas. The current assessment period includes three projects: REMOTE, RoRePower and EVERYWH2ERE. The projects are exploring the application of PEM, solid oxide and alkaline hydrogen technologies (FCs and electrolysers) for off-grid applications and also urban areas.

Turbines, boilers and burners: This is a new area aligned with the SRIA goals. Gas turbine and burner technologies present a valuable opportunity to repurpose existing infrastructure, thereby minimising expenses for new investments and ensuring a cost-effective transition to renewable gases and zero-carbon power generation. These technologies do not demand high purity levels in fuel gas and can tolerate trace amounts of other substances, allowing for cost- and energy-efficient production and promoting large-scale hydrogen conversion technologies. By 2030, the goal is to have 100 % hydrogen-ready European gas turbines and burners meeting emissions standards and providing zero-carbon, sustainable dispatchable power and high-temperature heat.

This area encompasses six projects dealing with combustion of hydrogen, ammonia and NG or their mixtures in combustors of gas turbines or in burners or boilers: FLEX4H2, HELIOS, ACHIEVE, H2AL, HyPowerGT and HyCoFlex.

Other research areas: This research area includes two projects assessed in 2024: WASTE2WATTS and RUBY. Both projects are exploring the use of SOFC technology; RUBY also considers PEMFCs.

Highlights

Focusing on alternative fuels, the ability to operate on a large variety of fuels, allowing for a 0 % to 100 % hydrogen operational range, including purified biogas, has already been explored in the SO-FREE project and the WASTE2WATTS project. The potential to use integrated biogas SOFC CHP systems with minimal gas pre-processing, focusing on low-cost biogas pollutant removal and optimal thermal system integration, has been demonstrated. Despite developing smaller and simplified systems (1.5 kWe instead of 6 kWe), WASTE2WATTS has added significant value by generating a substantial amount of cell field test results for publication in various research journals. Moreover, the project aided in identifying a business opportunity for SolydEra, an OEM which intends to commence production of 10 kWe stacks that can be combined to offer 50-300 kWe SOFC systems, including systems designed for the biogas market. Fifty kWe (50kWe) systems have been identified as a promising market segment with relatively low competition from engines. The cost calculation for gas cleaning should be improved using data from further field tests, and alternative gas cleaning methods (other than solid sorbents) are currently being explored.

COMSOS aimed to validate and demonstrate FC-based CHP solutions using NG in the mid-sized power ranges up to 60 kW. The primary innovation result of the project focuses on optimising FC systems, advancing standardisation and reducing expenses. Despite encountering challenges, the FC solution demonstrated better efficiency and emission levels than conventional technologies. The future commercial prospects appear promising. However, additional demonstration is required to obtain more accurate KPI measurements for FC-based CHP solutions in the mid-range power sector using biogas or hydrogen.

The concept of utilising reversible FCs to provide flexibility within the energy system and enable connections among different energy sectors, such as gas and electricity grids and heating networks, has been explored in the SWITCH project, building on the system developed in the CH2P project. The SWITCH system is a stationary, modular and continuous multi-source hydrogen production technology designed for HRSs. SWITCH demonstrates potential as a key technology for the transition to zero-carbon mobility in Europe. It targets both economic and continuous hydrogen supply at HRSs, contributing to the transition to a zero-emission mobility and energy system.

PACE saw the largest market introduction trial of m-CHP FC technology and provided a strong basis for the success of the Clean Hydrogen JU programme. The project is a success story and one of the flagship projects of the JU, assuring excellent large-scale validation of PEM and solid oxide technologies with around 23 million hours of operation, 3 400 installers trained and almost 24 million kW of electricity produced during the duration of the project, all of which makes it possible to learn from the experience.

REMOTE, RoRePower and EVERYWH2ERE have successfully demonstrated hydrogen-based P2P systems, promoting cost-effective decarbonisation and energy independence for remote areas, off-grid power generation in challenging climatic conditions and use of hydrogen FC generators at various events and locations across the EU, including cold ironing demonstration in the Port of Tenerife. These projects showcased advancements in clean energy solutions and contribute to reducing emissions in different applications and locations.

For the provision of HT heat for industry, the use of low-carbon hydrogen in burners and boilers appears to be better placed than other low-carbon and renewable solutions. All related topics in the 2023 call had successful proposals. As already mentioned, six projects are included in the present assessment and will deliver data in the next few years.

In the face of challenges like the COVID-19 pandemic, financial constraints, increased material costs due to the Russia-Ukraine war, tough climate conditions and alterations in demonstration sites necessitating changes in project plans, the projects still succeeded in showcasing the resilience and effectiveness of installed FC units through field tests, providing evidence and data on reliability, service and maintenance. This proved that European OEMs of both PEMs and SOFCs could provide reliable and robust remote power generation solutions for challenging conditions.

Gap analysis – main JRC recommendations

Promising results have been achieved as regards electrical efficiency targets for both PEMFCs and SOFCs, as well as CAPEX targets. However, further advances are needed to meet durability and reliability KPI targets, as well as those for maintenance costs and land use footprint. Additional progress is required for achieving KPI targets for small and mid-size SOFCs with regard to tolerated hydrogen content in NG.

The demonstration projects focused on remote locations and back-up power generation can serve as valuable foundations for future initiatives. Development of commercial/industrial-scale CHP units and/or prime power units by European suppliers (100 kWe – several MWe scale) should be pursued. For industrial heat and power development, prototypes for the smart cogeneration of industrial heat and electricity by FC CHP at 1, 10 and 100 MW scales should be developed, specifically targeting selected industrial environments.

Stationary FCs can play a crucial role in security of supply under exceptional circumstances, such as natural disasters, as well as in the context of global instability and geopolitical unrest. The lessons learned from existing projects can be applied to enhance the development and deployment of stationary FCs in these critical applications. Through exploration and development of FCs that run on alternative gases, the technology can become more versatile and adaptable to various applications and energy sources, enhancing its overall potential and value in the energy landscape.

5.5. PILLAR 5: CROSS-CUTTING ISSUES

This pillar contains specific supporting activities which play an enabling role to reinforce Europe's leadership position, accelerate mass-market adoption and maximise contributions to the achievement of decarbonisation targets. In line with the SRIA, the multi-annual project portfolio contains the following research areas:

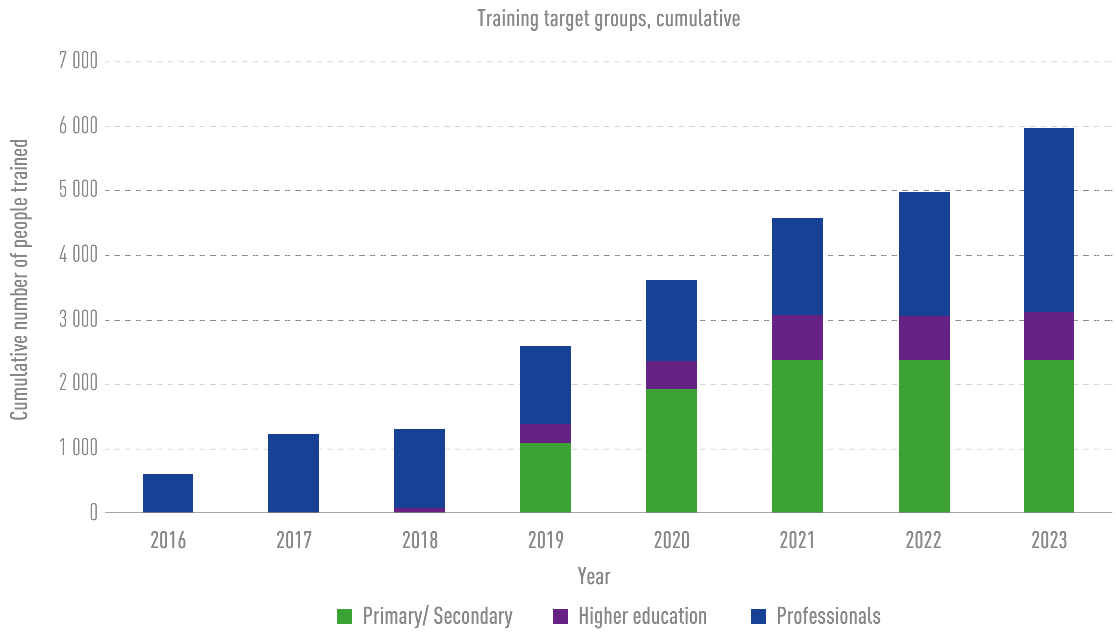
1. sustainability, LCSA, recycling and eco-design aspects;
2. education and public awareness;
3. safety, PNR and RCS.

Overview of research areas

Sustainability, LCSA, recycling and eco-design: In 2023, two new projects were funded in this area: HyPEF and NHyRA. HyPEF represents the natural progression from the SH2E project, with the goal of developing product environmental footprint category rules tailored to FC and hydrogen products. This will facilitate future benchmarking and ranking of FC and hydrogen products entering the EU market. NHyRA, on the other hand, is set to tackle the increasing concerns about the potential climate impact of hydrogen losses. On this issue, the Clean Hydrogen JU hosted a workshop in 2022 in collaboration with the United States Department of Energy to ascertain the current understanding and to assess the need for action and further research in this respect. A key takeaway from the workshop was the recognition that additional research is needed to quantify the extent of hydrogen emissions across the value chain. The NHyRA project will attempt to address this research gap.

Education and public awareness: HyAcademy.EU is a new project aiming to harvest previous results obtained by the FCH JU and develop a new approach based on creating networks of universities, schools and training institutions. The annual progress in terms of training attendees is shown in Figure 10.

Figure 10: Cumulative number of people trained, subdivided into categories: school pupils, higher education students and professionals



Source: Clean Hydrogen JU.

Safety, PNR and RCS: This research area is characterised by a high degree of publicly available outputs and of inter-project collaborations, including beyond the boundary of pillar 5, profiting from and interacting with other projects. Naturally, many of the results of these projects found their way into harmonised testing protocols, standards and technical regulations. Also, other projects allocated to pillar 2 will generate results in the RCS and safety area (HQE, OPTHYCS, HIGGS, CANDHY and RHeaDHy).

Highlights

The projects in this area could make a significant contribution to mitigation of the environmental impact of the design, production, use and end-of-life phases of FC and hydrogen technologies. The tailored LCA guidelines for FC and hydrogen technologies developed by SH2E are the first step needed to accurately assess the environmental impact of the technologies. The work HyPEF will perform is crucial to creating a benchmark for the environmental impact of hydrogen technologies and for the development of EU sustainability policies targeting this category. At the same time, the work done by eGHOST and BEST4HY is important to provide guidance on how to improve the design and end-of-life phases of FC and hydrogen technologies. Finally, the NHyRA project will provide essential information on hydrogen release to better understand the potential climate impact of hydrogen technologies. The collaboration that NHyRA has initiated with the other EU-funded project (HyDRA) focusing on a complementary topic – the climate implications of hydrogen emissions – is positive.

The Clean Hydrogen JU has now developed tools and methods addressing the specialised knowledge and skills needs of a broad range of users, from technicians and professional operators to universities, local and national authorities and public safety officials, and also including generic awareness raising in schools. Among recent achievements, the first MSc programme dedicated in its entirety to FC and hydrogen themes has been accredited and started in 2021-2022. Also, the HyAcademy.EU project and the eventual establishment of a European Hydrogen Academy represent the implementation of one of the provisions contained in REPowerEU, addressing the skilled workforce gap.

A recent Clean Hydrogen JU report measured Europeans' awareness of hydrogen technologies by means of a survey covering a sample of approximately 1 000 citizens in each EU Member State. The results showed that a great majority of the sample is aware of hydrogen energy and has a positive image of hydrogen in terms of environmental impact. A fair majority also perceives hydrogen as safe[48]. On top of that, the new HYPOP project specifically addresses policy stakeholders by exploring effective ways of involving stakeholders, including communication strategies and engagement activities.

The protocols for HDV refuelling developed by the PRHYDE project will be validated at a high-flow refuelling station to be deployed under the RHeaDHy project. It is expected that RHeaDHy will also provide recommendations for the improvement of the high-flow refuelling protocols. This is a good example of mutual reinforcement between pillars.

Mature liquid hydrogen technology is considered an enabler for the delivery and storage of large quantities of hydrogen. The PRESLHY project has taken an important step forward in terms of understanding of the behaviour of liquid and cryogenic hydrogen during its release into the environment. The ELVHYS project, which is just starting and is dedicated to transfer of liquid hydrogen, will further support progress in technical knowledge and possibly handling skills.

Gap analysis – main JRC recommendations

Sustainability, LCSA, recycling and eco-design: Looking at the EU policy framework to understand how the results of projects could be integrated into current and future directives is very important. HyPEF is a step forward in this direction, but it is crucial to highlight potential differences with the current methodologies proposed by EU policies to assess the environmental impact of hydrogen production (e.g. RED II, Taxonomy, CBAM). This should be followed by a harmonisation exercise to avoid confusion and discrepancies in the LCA results for hydrogen technologies caused by the adoption of different methodologies.

48 Awareness of Hydrogen Technologies - Survey Report (europa.eu), 2023

The European Hydrogen Sustainability and Circularity Panel should put in place a structure to monitor and assess the sustainability activities of the projects. It could also create a benchmark for the environmental impacts of the different hydrogen technologies.

Education and public awareness: HyAcademy.EU received considerably higher funding than previous projects under this research area, although the magnitude of the challenge identified at European level does not seem to be matched by the financial envelope and length of the project. It will be necessary to follow the progress of HyAcademy.EU very carefully to be able to identify obstacles in a timely manner and to react to avoid the pitfalls that occurred in previous projects. Another crucial success criterion will be the capacity of the project to align and integrate with wider EU support for skills development. Also, for the HYRESPONDER project, it would be good to exploit further the available training materials. Finally, tools like the engineering calculation tool, eLaboratory, developed by HYRESPONDER are hidden and therefore unknown to potential users. Easier and broader accessibility should be provided, which should probably be a task for the EHSP.

Safety, PNR and RCS: Further attention has to be dedicated to RCS and PNR for handling (storage, transport, delivery) large quantities of hydrogen, both in its compressed and liquid state. To achieve maximal impact, future Clean Hydrogen JU efforts must be placed within a wider framework of other EU- or Member State-funded activities, especially in the area of hydrogen transport by pipeline; laboratory-scale experiments will not deliver the knowledge and the data required to fully understand large transfer phenomena and risks. Large projects dealing with large hydrogen quantities will start shortly (IPCEI, ETS Innovation Fund, etc.), and the development of a vice-versa sharing and spill-over mechanism able to exploit these additional sources of data and experience to enrich Clean Hydrogen JU PNR and RCS activities and provide useful insights to these projects would be beneficial if confidentiality issues are adequately addressed (e.g. for IPCEI projects).

Also, the European Hydrogen Safety Panel (EHSP) must continue working and practicing on the tools and plans developed previously, for example the European Hydrogen Incident and Accident Database (HIAD 2.0) and its structural upgrade to HIAD 3.0, by developing efficient collection, updating, validation and analysis methods for new events.

5.6. PILLAR 6: HYDROGEN VALLEYS

The hydrogen valley concept has become a key instrument for the European Commission to scale up hydrogen technology deployment and establish interconnections between hydrogen ecosystems. The REPowerEU plan has allocated an additional EUR 200 million to the Clean Hydrogen JU to expedite the development of hydrogen valleys in Europe, aiming to double their number by 2025.

On 24 June 2024, the European Commission published a European roadmap for hydrogen valleys to assist European stakeholders in their development[49], also identifying the key barriers. Hydrogen Europe has published a position paper on the roadmap[50]. The key recommendations from Hydrogen Europe cover aspects such as providing guidance on the best locations, a simplification of processes and accelerated legislative transposition of energy and climate laws in Europe. Other sources of input to the roadmap were the European Regions Research and Innovation Network (ERRIN) report[51], which identifies the guarantee of robust involvement of local and regional stakeholders as one of the primary success factors for influential hydrogen valleys. Also, the Clean Air Task Force (CATF)[52] recommends focusing on the end-use sectors with the most benefit, such as the industries currently using grey hydrogen. It identified the refining and petrochemical, ammonia, methanol and steel production sectors as priorities[53].

49 https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13875-REPowering-the-EU-with-Hydrogen-Valleys-roadmap-_en

50 https://hydrogeneurope.eu/wp-content/uploads/2023/09/HE-Input-to-H2V-Roadmap_final-version-.pdf

51 https://errin.eu/system/files/2023-09/202309_Hydrogen%20roadmap%20_ERRIN%20input%20paper.pdf

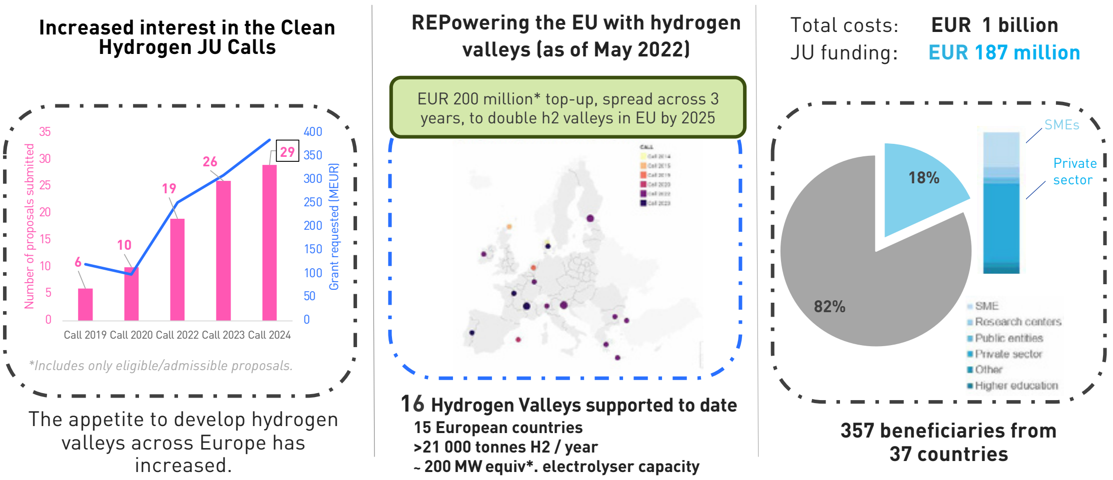
52 https://cdn.catf.us/wp-content/uploads/2023/11/02155931/roadmap-deployment-eu-hydrogen-valleys.pdf

53 https://www.catf.us/2023/10/moving-application-action-priority-focus-areas-does-regional-clean-hydrogen-hubs/

Another important initiative, the European Hydrogen Valleys S3 Partnership[54], was launched in 2019.

Building on the hydrogen territory concept introduced in the 2015 call (BIG HIT), the Clean Hydrogen JU has supported the demonstration of hydrogen valleys since 2019 (Figure 11).

Figure 11: Overview of Clean Hydrogen JU support of hydrogen valleys



* This is an estimated equivalent electrolyser capacity calculated using the H2 production requirements of the Call topics. The 'to be installed' capacity may differ.

Source: Clean Hydrogen JU.

In addition to the support for the deployment of hydrogen valleys via its calls for proposals, the JU is helping to create a pipeline of hydrogen projects (including hydrogen valleys) via its dedicated PDA initiative. The second implementation of this initiative, PDA II, ended in March 2024. In total, 14 regions received PDA support. A final report has been published (see also Chapter 8)[55]. A call for tenders has been launched for a hydrogen valleys facility[56], to expedite the development of hydrogen valleys in Europe by continuing to offer technical, financial and legal support through PDA to both public and private stakeholders.

To enable structured cooperation between the Clean Hydrogen JU and managing authorities of Member States and regions, the JU awarded a contract to design a collaborative approach for R&I activities. In 2023, an analysis of hydrogen R&I policies in Member States and HE-associated third countries was conducted, followed by a call for expressions of interest to select 10 regional or national managing authorities for tailored cooperation. A meeting was held with the chosen authorities during Hydrogen Week 2023, and the development of memoranda of cooperation began. Three memoranda of cooperation were signed in June 2024, during the European Hydrogen Valleys Days[57]. The others will follow in the second half of 2024.

Additional information on the work that the Clean Hydrogen JU is doing with regions can be found at the Clean Hydrogen JU website[58].

54 https://ec.europa.eu/regional_policy/policy/communities-and-networks/s3-community-of-practice/partnership_industrial_mod_hydrogen_valleys_en

55 https://www.clean-hydrogen.europa.eu/media/publications/final-report-project-development-assistance-regions-ii-cohesion-countries-outermost-regions-and_en

56 https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/tender-details/424246ca-5b16-41b0-8bd0-355c769a396a-CN

57 https://www.clean-hydrogen.europa.eu/media/events/hydrogen-valleys-days-2024-06-17_en#:~:text=The%20agenda%20features%20discussions%20with,Valleys%20in%20the%20European%20Union

58 https://www.clean-hydrogen.europa.eu/get-involved/working-regions_en

Highlights

The large-scale valleys will have a high impact due to their visibility and will contribute to reaching the EU and SRIA goals. There is an increased focus on end-use, which is a positive step forward. For the small-scale valleys, there is a good deal of variety in terms of end-use applications, which will help to further develop valley archetypes that can then be replicated.

The high number of valleys initiated in the last two years shows the commitment of the project partners, as well as of the communities and regions, to this concept. Even though funding rates are generally low, the participants are either investing heavily themselves or making the effort to secure additional (public) funding. Several projects have strong links to other initiatives and in some cases are utilising infrastructure developed by other projects.

Infrastructure is being created for hydrogen delivery and storage, which will benefit other hydrogen initiatives in the region. Also, digital tools are being developed to increase synergy and optimise performance between different steps of the value chain: specifically renewable energy production, hydrogen production and storage, and end-use. At least five projects are developing digital tools to support replicability.

Gap analysis – main JRC recommendations

Getting co-financing consumes a lot of resources and causes delays. Ambitions remain high, but coordination efforts are needed to facilitate combination of EU and national/regional funding to reduce the remaining financing requirements, so that they can, at least in large part, be borne by industry partners. This would lead to more stability, both in the planning and implementation phase.

Additional coordination is also needed in developing digital tools to support replicability. All the work should be channelled into fewer tools (possibly differentiated by the size of the valley or other specificities) to avoid confusing the intended users by offering a range of similar tools. The hydrogen valleys facility could contribute to this. These enhanced tools could be made available on the Mission Innovation Hydrogen Valley Platform.

Projects could benefit from further support during their implementation, for example regarding the connection of hydrogen valleys to each other and to other relevant initiatives[59]. Coordination between valleys is facilitated by the platform, but links to other types of projects should be fostered, in particular to large-scale demonstration projects funded through HE or IPCEI initiatives. Another aspect related to multiplying the impact of hydrogen valley deployment is that valleys should ideally be located close to Trans-European Transport Network corridors, suitable geological formations for hydrogen storage and newly built RESs, as well as to hydrogen consumers.

Finally, training and education is seen as a potential bottleneck by hydrogen valley stakeholders. It has been recommended[60] that any investments related to the deployment of hydrogen valleys should be accompanied by investment in human capital.

5.7. PILLAR 7: SUPPLY CHAIN

Considering the massive hydrogen production levels targeted in the coming years, a considerable increase in numbers of companies with the requisite expertise is required along the supply chain. The supply chain includes everything from processing of raw materials into specialised materials (e.g. electro-catalysts) and production of components and sub-systems to system integration. The supply chain is also complemented by the wider value chain approach vis-à-vis creation of jobs, added value to the economy and industrial competitiveness.

Noticeable improvements, obtained with innovative FC manufacturing methods, can be detected for many KPIs linked with performance, such as efficiency, FC stack durability, FC module availability, minimum platinum use

59 H_2 Valleys Workshop Outcomes.pdf (europa.eu).

60 https://www.clean-hydrogen.europa.eu/system/files/2023-05/H2%20Valleys%20Workshop%20Outcomes.pdf

and CRMs/PGMs recycled from scrap and waste. However, CAPEX is a crucial parameter which is still beyond reach.

The main objectives of this pillar can be summarised as:

1. identification of potential vulnerabilities in European hydrogen supply chains;
2. development of new and improved manufacturing technologies and production processes that facilitate the safe and sustainable use of non-critical (raw) materials and adoption of circular economy principles;
3. reduction of the use of critical (raw) materials with sustainability or environmental concerns, such as those deriving from poly/perfluoroalkyls.

The R&D priorities address early-stage development research actions and demonstration actions. Early-stage development is mostly focused on new manufacturing technologies and automation of production processes. The development research actions mostly focus on addressing the bottlenecks along the hydrogen supply chain (e.g. critical components and sub-system supply), manufacturing training and skills, integration of new manufacturing technologies, use of artificial intelligence, etc. As for demonstration actions, they should address the development of medium-sized and large-scale manufacturing capacity, as well as development of pan European technology (testing) platforms based on the gap analysis of the supply and value chains study.

Highlights

European companies and research organisations are leaders in many segments along the hydrogen supply chain, which gives Europe a competitive advantage over other key players such as Japan, South Korea, the USA and, more recently, China. However, this leadership must be preserved by constant effort to keep up with R&I actions able to fill existing gaps and mitigate vulnerabilities and to remain competitive at a global level.

An update of the 2019 EU supply/value chain study[61] for hydrogen and FC technologies has been conducted by the JU, identifying present weaknesses and proposing appropriate solutions. A summary report is expected to be released in autumn 2024[62]. Additional information on suppliers of FC systems and components, as well as service providers is also to be found at the European Hydrogen Observatory (EHO)[63].

Gap analysis – main JRC recommendations

The main segments of the supply chain, including the production of specialised/advanced materials, components and equipment, must be covered by European manufacturers. To a certain extent this is covered by the reviewed projects, but more effort is needed in that direction.

EU leadership on advanced materials and components used in hydrogen technologies should be reinforced by the contribution of the Clean Hydrogen JU activities (optimisation of the manufacturing processes, use of abundant natural resources, improvement of product quality – targeting zero-defect products, development of new architecture, reduction of the time to market through technological/research platforms, etc.). Projects dealing with materials research must collaborate closely with those focused more explicitly on manufacturing and upscaling of technologies.

5.8. PILLAR 8: STRATEGIC RESEARCH CHALLENGES

Previous roadmaps have highlighted early-stage research actions, which serve as the foundation for pinpointing the most significant strategic research challenges:

61 Value added of the hydrogen and fuel cell sector in Europe, FCH 2 JU, 2019.

62 To be published on the Clean Hydrogen JU website.

63 https://observatory.clean-hydrogen.europa.eu/directory

- low-PGM or PGM-free catalysts (including bio-inspired catalysts), reducing the use of critical (raw) materials in electrolysers and FCs, and ensuring the safe and sustainable use of all materials, including the development of PFAS-free ionomers and membranes;
- advanced materials and processes for hydrogen storage, such as carbon fibres, H2 carriers and additive manufacturing;
- enhanced understanding of the performance and durability mechanisms of electrolysers and FCs.

The three projects already started address topics ranging from establishment of eco-design guidelines and environmentally friendly manufacturing methods, to energy-efficient and lower-emission processes involving artificial intelligence, machine learning or other data management techniques and development of diagnostic models and standardisation of test procedures, with a focus on reducing the cost and increasing the lifetime of electrolysers.

Highlights

The three projects under pillar 8 focus on the three research areas specified for this pillar in the SRIA. While similar research issues have been addressed in other pillars, these projects are unique due to their lower TRL and long duration, with the aim being to resolve research challenges rather than develop and demonstrate concrete prototypes or systems. This makes these projects more transversal, covering multiple technologies instead of just one. Additionally, pillar 8 projects address multiple aspects and this multi-faceted approach distinguishes them from projects in other pillars. Given their transversal and multi-technology focus, the lessons learned from these pillar 8 projects can be applied and shared across different pillars.

Gap analysis – main JRC recommendations

The projects under pillar 8 have recently commenced, and as of now, there are not enough data or insights to conduct a comprehensive analysis. In the coming years, as more data become available, it will be possible to draw more concrete conclusions and inferences from these projects.

Considering the transversal, multi-faceted nature of these low-TRL projects, it is vital for research and technology organisations, especially SMEs, to have access to the appropriate tools and facilities to efficiently test their innovative products. This will enable them to contribute effectively to these projects and further their development.

Potential solutions include the use of the existing Open Innovation Test Bed platform, the Central European Research Infrastructure Consortium and the JRC Open Access Scheme, which can support projects in their research endeavours by facilitating collaboration and knowledge sharing across various research areas. This interconnected approach encourages innovation and advancement in research.

6. GENERAL JRC RECOMMENDATIONS

The JRC performs the annual assessment of the programme as a formal part of the regular improvement cycle of the Clean Hydrogen JU. Its main purpose is to provide feedback to the members of the Programme Office of the JU on performance in the research areas directly within their remits. It also informs the decisions of future annual work plans by identifying gaps and possible improvement actions. Over a multi-annual timescale, it assesses whether the adopted KPIs and their targets are fit for purpose, gathering improvement elements useful for their future updates. It also provides a fact-check basis which can be used by other programme technical assessments (for example the mid-term and the ex-post assessments). Finally, the data collection performed annually supports the assessment of long-term, historical progress of specific hydrogen technologies.

In general, the assessment concludes that the Clean Hydrogen JU activities have quickly and successfully been aligned with the recent R&I policy priorities as expressed in the Green Deal and REPowerEU. Although the projects forming the base of the 2024 programme technical assessment have been designed and are still funded under the former H2020 Programme, the expected stronger attention to renewable hydrogen production and selected end-use sectors has already emerged clearly. The supply chain topic has also been addressed via various projects in several pillars. This is an excellent demonstration of structural flexibility and capacity to align quickly with European Commission policy requirements. For example, since the new programme should be led by sustainability principles, the current projects are developing LCSA methodologies and approaches, which can be applied to all future projects. In line with the policy expectation regarding the role of hydrogen in the decarbonisation of hard-to-abate sectors, the FC development effort has shifted focus to solutions for long-haul, high-power transport sectors.

Regarding data collection, the project fiches represent an improvement of the data collection process in several ways: firstly, by including data previously dispersed across several sources and secondly, by being a living document where progress achieved through the years by projects can be traced. Nevertheless, to become a successful data collection tool, the willingness of the project coordinators to thoroughly fill in and frequently update each project fiche is vital, especially for information that cannot be shared in the project deliverables. This is particularly relevant for the successful implementation and deployment of the Knowledge Hub.

In the same sense, project reporting in TRUST needs to be further improved in terms of quality, as does the public accessibility of data, as much of the data currently submitted are labelled as confidential. A surprising finding was that, in many cases, data marked as confidential information in TRUST are actually publicly available from other sources (e.g. project websites and/or publications). This practise is hindering the monitoring and reporting of programme achievements, as well as the efforts by the JU to ensure projects continue making their data available via the data collection exercise. An effort to rationalise this practise on behalf of the data providers should be made in the new data collection platform that will replace TRUST in the Knowledge Hub.

The Clean Hydrogen Knowledge Hub, planned to be launched at the beginning of 2025, aims to improve the data collection interface and visualisation of data. It will collect and manage the knowledge produced by the Clean Hydrogen JU programme and its projects by coordinating access to non-confidential information by stakeholders, the scientific community and society in general. Results, methods and data will be available and structured in a central repository. This will address more adequately the lack of a coordinated action aimed at guaranteeing the widest possible sharing and accessibility beyond the end of individual projects and overcoming the fragmentation and dispersion of knowledge. Also, it is expected to resolve the long-standing issue of the lack of structured tracking of the outcomes at programme level when it comes to the use of key exploitable results. The Knowledge Hub will improve the collection of information on patent ownership and the domiciliation of research activities to allow for a better assessment of how the JU-funded research translates to industrial level.

Projects often report delays during implementation for recurring reasons. For example, large-scale demonstration projects often find it difficult to get sufficient demonstration time, due to permitting or operational requirements at industrial sites, changes in technology providers and/or demonstration sites, and delays accumulated during prototype development. Sharing the lessons learned from other European initiatives like projects of common interest and Innovation Fund projects, and, at Member State level, IPCEIs, could allow for more accurate and reliable planning depending on case-by-case specificities.

Also, permitting processes and approval from local authorities for field-test activities differ between locations, and the lack of technical knowledge of local administrations may lead to significant delays (e.g. the case of EVERYWHERE). Type approvals for retrofitted trucks/coaches can be also challenging (e.g. for COACHYFIED). A hydrogen-specific and harmonised EU regulatory framework would solve or at least strongly mitigate this shortcoming, but its realisation is hindered by the differences in EU Member State legal frameworks.

All projects must continue integrating sustainability and circularity principles and adopt the tools developed in pillar 5 and by the JRC, such as the LCA checklist, as references for measuring sustainability. The Knowledge Hub is expected to allow for monitoring and assessment of the sustainability activities of projects by systematically collecting relevant data for environmental and social assessments.

Synergies with other programmes and coordination with other initiatives, especially CINEA, projects of common interest, Innovation Fund projects, etc., are recommended for exchange on technical issues for the low-TRL projects and to share lessons learned for the demonstration projects. Further discussions would be useful on how high-TRL projects could work together and how the Hydrogen Knowledge Hub can be best used for this purpose. Also, the JU role as a catalyst for bringing innovation from lab to industrial scale should be crucial in levelling the playing field when it comes to the identification of public/private synergies.

In alignment with the Green Deal industrial plan, research activities related to the scaling up of manufacturing capacities for all technologies in this programme are becoming even more important. Even low-TRL activities should present ideas or challenges for upscaling. This continuation of support for novel technologies promotes their potential market readiness. The JU programme must also remain aligned with the new objectives and targets of the CRM Act and adopt the established and agreed-upon thresholds from the Net-Zero Industry Act for equipment, materials and component procurement to further enhance European manufacturing capabilities.

7. WIDER SCIENTIFIC COMMUNITY CONSULTATION

The Clean Hydrogen JU aims to continuously progress towards the objectives reflected in the SRIA by trying to involve as many of the stakeholders of the hydrogen technologies sector as possible. Actions undertaken by the Clean Hydrogen JU should consider not only the views of its public and private members, as well the recommendations coming from the JRC, reflected in its programme annual assessment and summarised above, but also the views of the wider scientific community[64].

In this context, the JU conducted a survey, both in 2023 and 2024, addressing the wider scientific community to gather feedback on the SRIA topics and the implementation through the annual work programmes implemented so far. The 2024 wider scientific community survey was launched in the EUSurvey platform on 11 April 2024. It was initially planned to be concluded by 9 May but was finally extended twice, concluding on 19 May 2024.

Building on the learnings from the 2023 wider scientific community survey, there were efforts: (a) to improve the content of the questionnaire to make it more targeted and user friendly; (b) to reach out to the right audience by any means, including social media and e-mails to those participants from the 2023 exercise who gave their consent for their contact details to be retained to enable them to participate in the 2024 survey as well; and (c) to expand its timespan by extending its deadline twice. Despite these efforts, participation eventually proved too low. Only 13 replies were submitted, which doesn't correspond to a statistically significant population; any attempt to analyse them might thus lead to outcomes that are not representative of the overall scientific community audience. In this respect, the JU decided to archive the survey and proceed neither with the analysis nor with a new survey in 2025. Other forms of consultation will be examined to ensure that they remain in line with Article 82(d) of the SBA.

64 According to SBA Article 82(d), the Governing Board of the JU must ensure that independent opinions and advice of the wider scientific community on its SRIA, work programmes and developments in adjacent sectors are gathered through an independent scientific advisory workshop as part of the European Clean Hydrogen partnership forum.

8. RECENT STUDIES ON HYDROGEN TECHNOLOGIES

Several actions complement the project funding activities of the Programme Office, including recent studies related to the programme objectives, with interesting results reflecting recent developments in the hydrogen sector. These studies were published between the last semester of 2023 and September 2024 and were either procured by the JU or performed by international organisations.

The study on hydrogen in ports and industrial coastal areas[65] was concluded at the end of 2023, with three reports published in total, in March, September and December 2023. The first report uses a scenario-based approach to provide detailed outlooks for potential hydrogen supply and demand in European ports and coastal areas in 2030, 2040 and 2050, along with the required hydrogen value chain infrastructure and a no-regrets investment roadmap. It also provides an overview of the various possible roles that a port could fulfil in Europe's future hydrogen economy. The second report aims to inform relevant port-related stakeholders (including policymakers) about required non-technical (policy, regulatory, governance, strategic, etc.) enablers, areas of priority for R&I projects and required safety RCSs for the timely development of hydrogen-related activities and infrastructures in EU port ecosystems. The third report examines several case studies (Port of Klapeida, Lithuania; Port of Antwerp-Bruges, Belgium; Port of Duisburg, Germany; Port of Livorno, Piombino and Portoferraio, Italy; Port of Pecém, Brazil; and Port of Rotterdam, the Netherlands) highlighting the techno-economic feasibility of developing a range of hydrogen-related activities and infrastructures in the vicinity of ports.

In November 2023, in the context of the technical assistance provided to generate synergies with Member States and regions, a report was published covering the national and regional/local hydrogen strategies of the EU-27, as well as of the HE associated countries with representatives in the Clean Hydrogen Joint Undertaking State Representatives Group (JU SRG)[66]. The document combines the information retrieved via literature review with the information provided by the SRG representatives both via the tailor-made questionnaire and interviews.

The main takeaways regarding the targets underline that the main focus of the national H_2 strategies is on installed electrolyser capacity, while only a limited number of targets focus on domestic RES H_2 production, numbers of HRSs or H_2-fuelled vehicles. Also, national authorities should stress the link with national RES generation capacity more. In terms of funding instruments, despite the general openness of national programmes to co-funding, further collaboration is necessary to enable synergies between the different funding opportunities and increase their impact. Finally, policy initiatives and measures (including tax incentives at national level) should remain in line with the REPowerEU target of 10 million tonnes of domestic renewable hydrogen to facilitate the manufacturing scale-up of commercially available low-carbon technologies, equipment and components.

In March 2024, a technical report was published providing a comprehensive historical analysis of the Clean Hydrogen JU projects focused on Fuel Cell Electric Vehicles (FCEVs), Fuel Cell Electric Buses (FCEBs) and associated HRSs within the European Union[67]. The report underscored the potential of hydrogen mobility for achieving ambitious decarbonisation targets and building a resilient, efficient and low-carbon future for European transport. The cumulative level of EU funding from the Clean Hydrogen JU for FCEVs, FCEBs and the associated HRS demonstration projects is shown in Figure 12. As of 2023, the cumulative EU funding value for

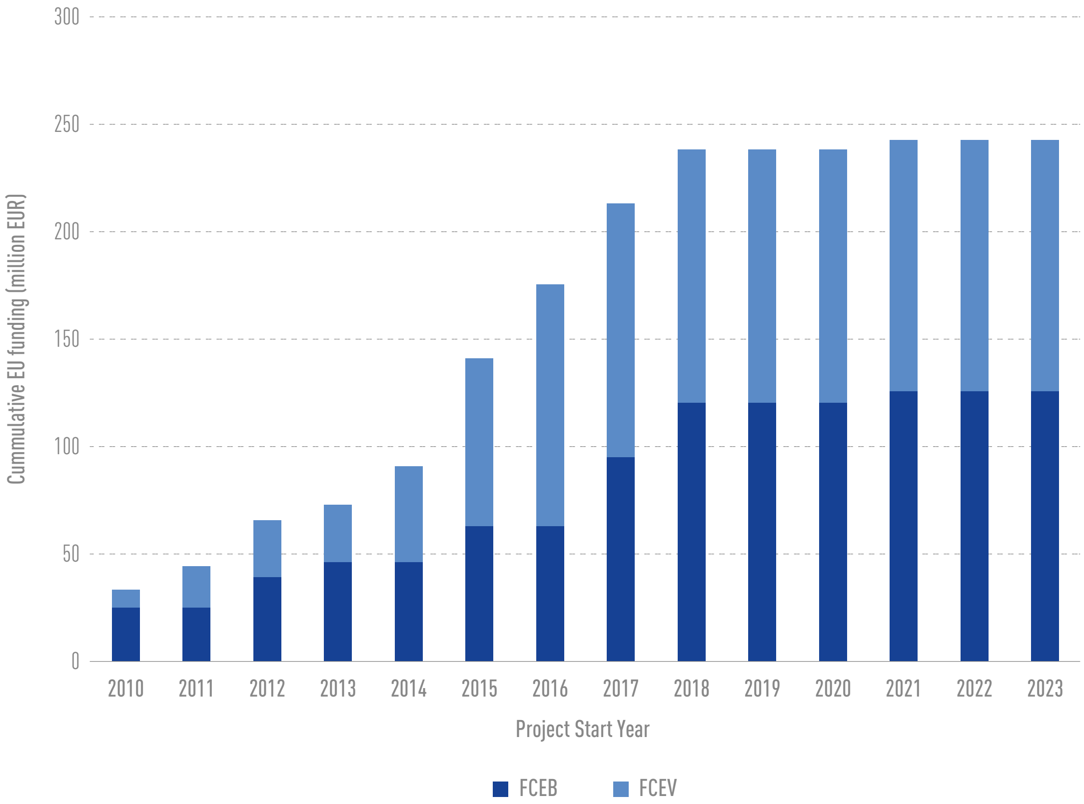
65 https://www.clean-hydrogen.europa.eu/media/publications/study-hydrogen-ports-and-industrial-coastal-areas-reports_en

66 Generate Synergies with Member States and Regions : Assessment of hydrogen policies and funding strategies: https://www.clean-hydrogen.europa.eu/media/publications/generate-synergies-member-states-and-regions-assessment-hydrogen-policies-and-funding-strategies_en

67 Historical Analysis of Clean Hydrogen JU Fuel Cell Electric Vehicles, Buses and Refuelling Infrastructure Projects: https://www.clean-hydrogen.europa.eu/media/publications/historical-analysis-clean-hydrogen-ju-fuel-cell-electric-vehicles-buses-and-refuelling_en

FCEBs was close to EUR 126 million while the cumulative funding dedicated to FCEV demonstration projects was approximately EUR 116 million.

Figure 12: Cumulative level of Clean Hydrogen JU funding versus project start year for FCEV, FCEB and HRS technologies



Source: JRC based on data from Clean Hydrogen JU, 2023.

The market penetration of FCEVs was accelerated by the Clean Hydrogen JU projects (under H2020), demonstrating market readiness and identifying business cases, as well as developing the necessary refuelling infrastructure at a competitive cost (Figure 8). The total number of FCEVs deployed during this timeframe passed the benchmark of 1 300 units, laying the foundation for the first genuinely pan-European network and the establishment of the world's most extensive HRS network.

A major advantage of FCEBs is the longer distance range they can achieve in comparison to battery electric buses. At a European level, the Clean Hydrogen JU bus deployment activities can be considered as a flagship (Figure 7). The number of FCEBs deployed during this period surpasses the 400-unit milestone. The success of bus demo projects is demonstrated by the fact that in different cities, bus operators have joined the projects after their launch. This is evidence of a growing involvement of regions and a steady increase in private contributions to the financing of the demo projects.

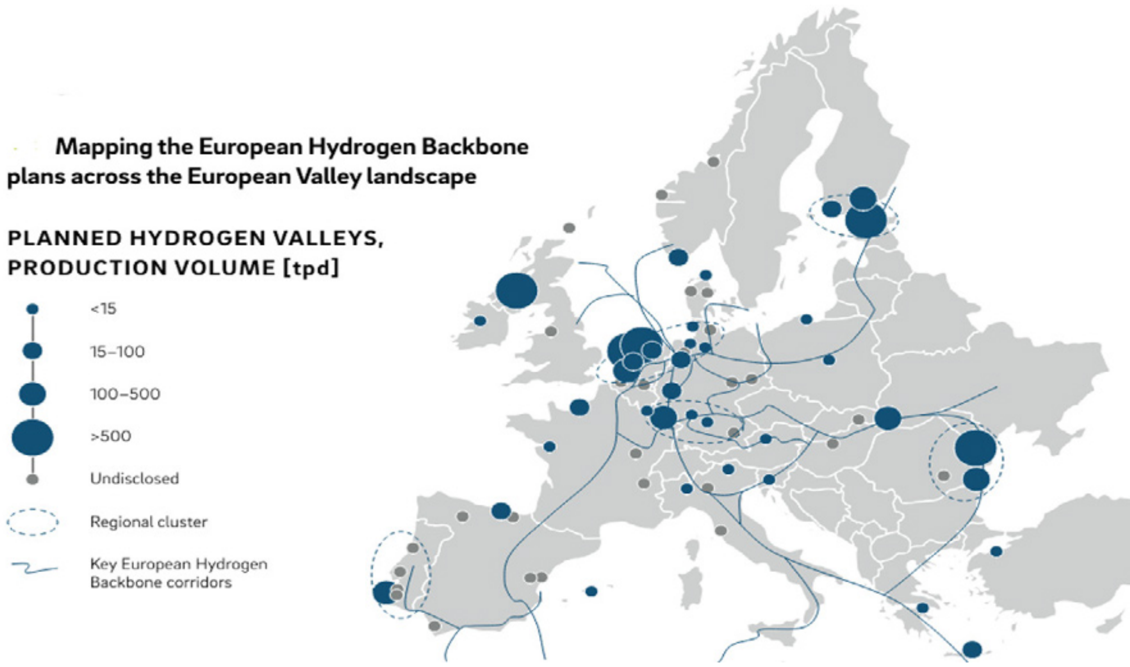
Main takeaways highlight that challenges persist. Both FCEVs and FCEBs face competition from battery electric alternatives, which benefit from lower operational costs and advances in technology. The energy crisis of 2022 has further impacted the financial viability of hydrogen-powered transport by increasing hydrogen fuel costs. Another issue is that the supply chain for components remains fragile: there is limited flexibility to ramp up production or expand spare parts inventories. Specific challenges for FCEBs include long manufacturing times and the slow development of 'package solutions' for hydrogen refuelling infrastructure.

Based on the final report on PDA for Regions II, published in June 2024, a total of 14 different projects from cities and regions in nine different European countries were supported. Road transport applications, in particular buses, were the most common target end-use. The projects sought to develop new hydrogen production facilities, typically electrolysers at the low-megawatt/low-tens-of-megawatts scale for the initial phases of deployment, linked to existing and/or new-build renewable electricity generation assets (typically solar PV and wind turbines), as illustrated in Figure 13.

In June 2024, an updated report on hydrogen valleys and the Mission Innovation Hydrogen Valley Platform entitled *Making it happen: Hydrogen Valleys – Progress in an evolving sector*[68] published. This report analysed empirical evidence from hydrogen valleys globally over the last 3 years and discussed the development of the hydrogen valley concept and community, as well as the necessary framework conditions for its development. It also explored the more recent challenges faced by hydrogen valleys and the clean hydrogen sector as a whole, identified success factors for complex hydrogen project development and highlighted the remaining barriers to implementation that need to be overcome.

Apart from helping to bring down costs by combining and pooling demand of multiple end-users for larger-scale upstream production at lower costs, hydrogen valleys can also successfully diversify risks by sharing infrastructure (e.g. pipelines, HRSs). They are strategically located in clusters of hard-to-abate industries, metropolitan regions and logistics hubs and at the most attractive renewable energy locations, as also shown in Figure 13.

Figure 13: Mapping of European hydrogen backbone plans across the European valley landscape



Source: European Hydrogen Backbone, Hydrogen Europe, h2v.eu.

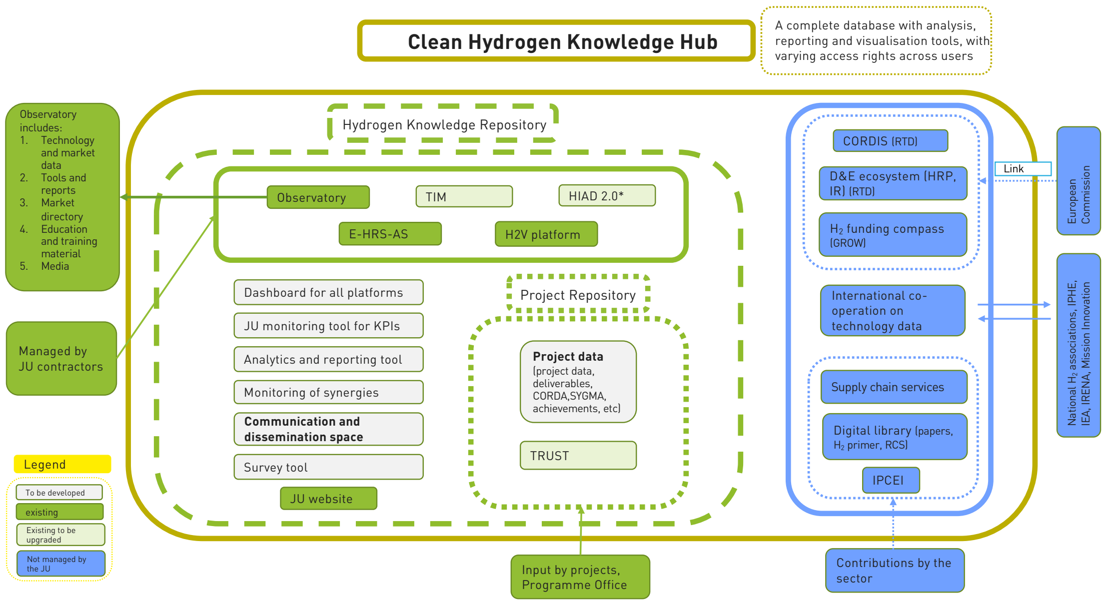
The report concludes with a call to action for project developers, policymakers and investors to continue advancing the hydrogen sector. Overall, it emphasises the importance of collaboration, adequate risk management combined with policy support, and investment to accelerate the global energy transition with the help of hydrogen valleys.

Finally, a major shift in the knowledge management operations of the JU and its stakeholders will come in the form of the new Knowledge Hub platform, a unique digital platform that is expected to provide the necessary capacity to better collect and manage knowledge concerning activities and funded projects of the JU programme, as well as to facilitate access to non-confidential information for its members and the wider public. The JU aspires to

68 Making it happen: Hydrogen Valleys progress in an evolving sector: https://www.clean-hydrogen.europa.eu/media/publications/making-it-happen-hydrogen-valleys-progress-evolving-sector_en

ensure that this platform will have access and be linked to various data sources and will be able to manipulate, analyse and visualise the information and data in order to allow Hub users to navigate through them based on their access rights. Figure 14 outlines the concept of the Knowledge Hub. A call for tenders was published in 2023 and a contract was signed at the end of that year. The platform is expected to be launched in 2025.

Figure 14: The Clean Hydrogen Knowledge Hub concept



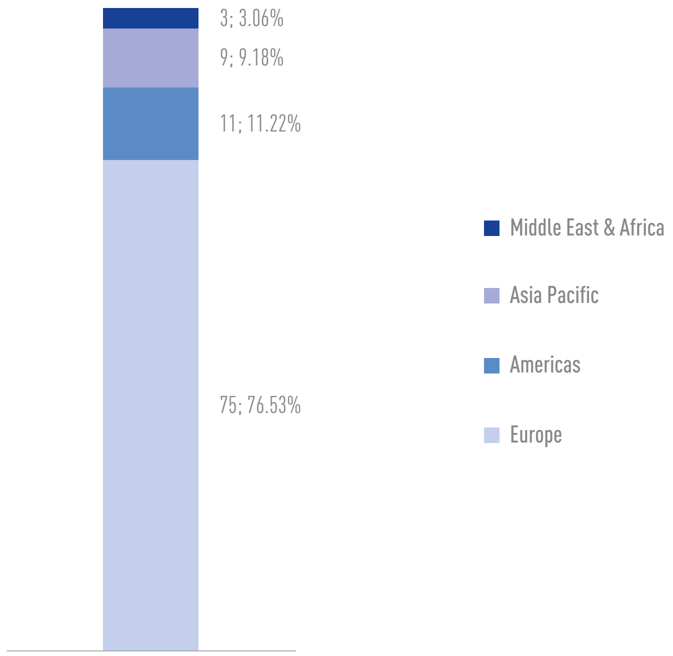
Source: Clean Hydrogen JU.

9. HYDROGEN TECHNOLOGY MARKET ENTRY BARRIERS

The Clean Hydrogen JU is tasked, in its founding regulation[69] with assessing and monitoring technological, economic and societal barriers to market entry, including in emerging hydrogen markets. This task can be challenging, considering that hydrogen is a promising energy carrier and also an important feedstock for certain industrial processes. Also, the hydrogen value chain is nascent, and the necessary components related to hydrogen production, storage, transfer/distribution and end-uses, mainly in transport and industry, have only just started being deployed and entering the market.

Many of the existing barriers have only just become known, most of them as impediments to the activities of Clean Hydrogen JU projects and the establishment of hydrogen valleys that combine activities across the whole value chain of the nascent hydrogen market.

Figure 15: Hydrogen valleys' locations



Source: Hydrogen Valley Platform (www.h2v.eu).

In order to identify such barriers, one should look at large-scale hydrogen flagship projects addressing production and consumption in multiple sectors of the economy. Hydrogen valleys constitute an ideal source for information related to market barriers that participants are facing in their efforts to deploy hydrogen technologies. Many hydrogen valleys in Europe and around the world choose to register their projects in the Hydrogen Valley Platform, providing valuable information regarding their activities and challenges related to setting up a hydrogen ecosystem from scratch. In September 2024, the platform listed 98 valleys in 36 countries worldwide, out of which 74 are in Europe (Figure 15). The 98 valleys have received total investment of EUR 173 463 million. The platform offers information on various aspects of the valleys, such as location or planned hydrogen production volume.

69 SBA Article 74 (a).

The Hydrogen Valley Platform collects information related to market barriers, separating them into three different categories[70]:

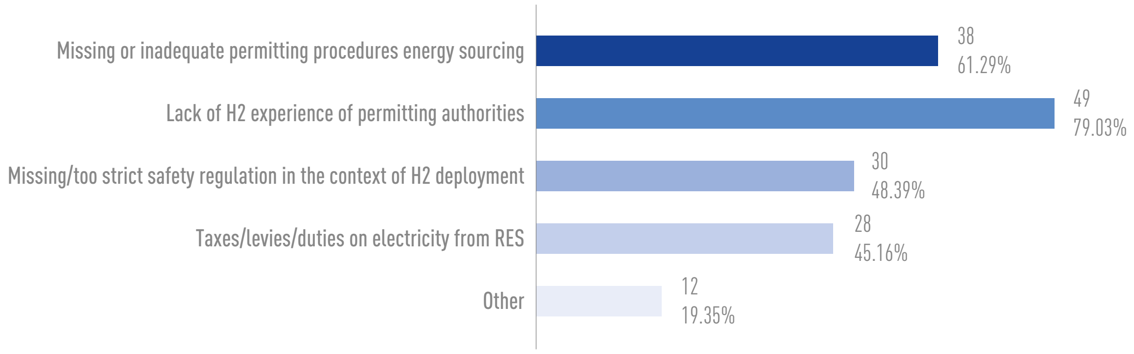
- regulation: inadequate hydrogen legal framework, as well as a lack of experience of permitting authorities with hydrogen projects;
- project development – preparation: barriers related to securing funding, developing a sound business case, obtaining permits and finding experienced staff;
- project development – financing: barriers related to securing public financial support and customer commitments.

The results from the surveys so far[71] are briefly presented by category below.

9.1. MAIN BARRIERS – REGULATION

Hydrogen valleys identify many regulatory barriers which reflect a lack of experience in hydrogen technologies among permitting authorities that might compromise their competence. This is anticipated due to the lack of expanding hydrogen markets so far. Also, non-existent or inadequate procedures or rather strict regulations related to hydrogen applications cause significant delays to projects, while the financial burdens imposed on renewable electricity also affect the financial decisions made by the project participants. Figure 16 shows, globally, how many valleys identify each of the different impediments as directly affecting their projects and what share of all valleys consider removing each of them as key for the success of their project.

Figure 16: Main regulatory barriers – global



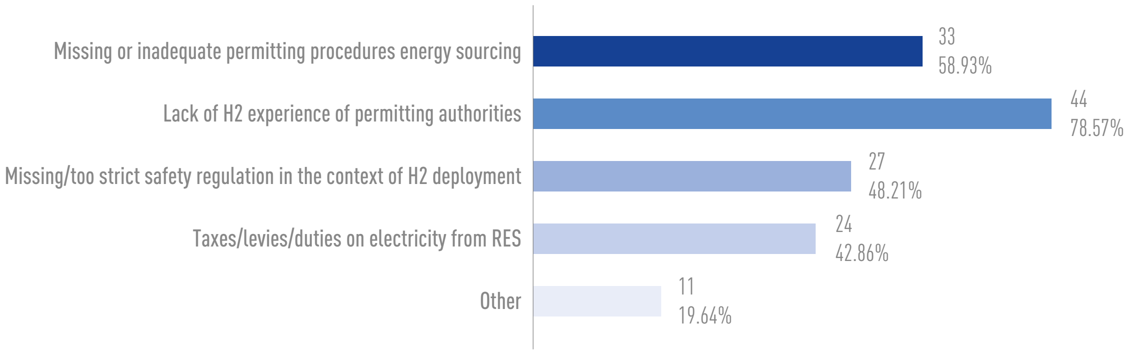
Source: Hydrogen Valley Platform.

Figure 17 focuses on the views of hydrogen valleys located in Europe, which are almost identical to the global view. As non-European valleys account for by far the smaller share of all valleys listed on the platform and only a few of them responded, conclusions can only be drawn safely on regulatory barriers in Europe. The most significant impediments are related to permitting: authorities lack experience in hydrogen applications and either permitting procedures are not in place or more effort is necessary to respond to market needs.

70 https://h2v.eu/analysis/barriers/regulation

71 Concerning 98 valleys at the time of the drafting of the text, 75 of them located in Europe.

Figure 17: Main regulatory barriers – Europe

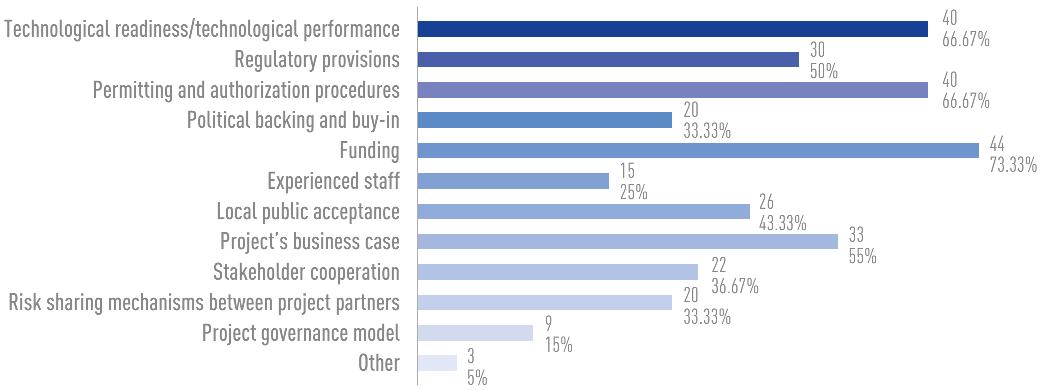


Source: Hydrogen Valley Platform.

9.2. MAIN BARRIERS – PROJECT PREPARATION

Project preparation is always a challenging process, but it becomes even more difficult in the case of hydrogen valleys due to the complexity of the planned ecosystem and the divergence between different business cases. Many different sorts of barriers and hurdles related to preparation have been identified by the projects, most of them related to funding, technological readiness of the hydrogen technologies, permitting and authorisation, and the business case of the project. Public acceptance, regulatory frameworks and political backing are also important in the process, together with mechanisms for risk sharing between project partners. Figure 18 shows, globally, how many valleys identify each of the different sorts of impediments as critical during the preparation phase and what share of all valleys consider them as key to the success of their project.

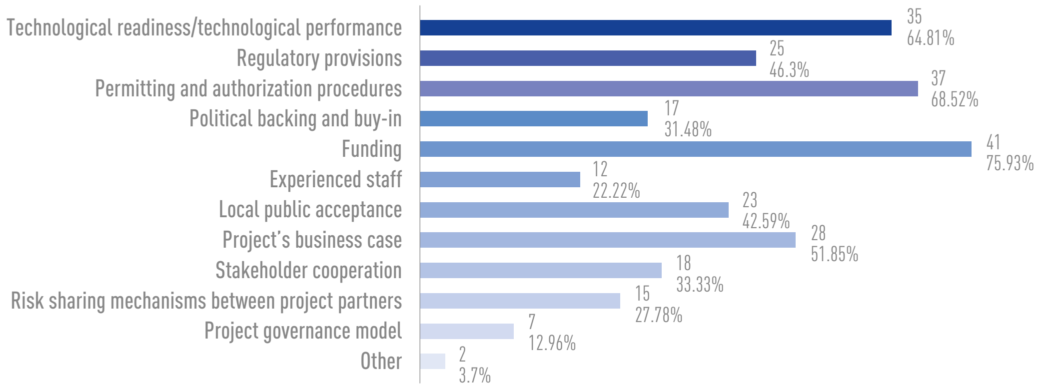
Figure 18: Main project preparation barriers – global



Source: Hydrogen Valley Platform.

American and Middle Eastern valleys are few in number compared to the European projects reported. Therefore, the valleys located in Europe dominate the sample in this case as well and thus highlight the most critical hurdles (Figure 19). Lack of funding is a strong indicator of the lack of a concrete business case: most of the valleys have great ambitions that require considerable investment, but there is still a lot of uncertainty regarding revenues. In the short term, public authorities will probably need to provide a lot of regulatory and permitting support to assist project development.

Figure 19: Main project preparation barriers – Europe

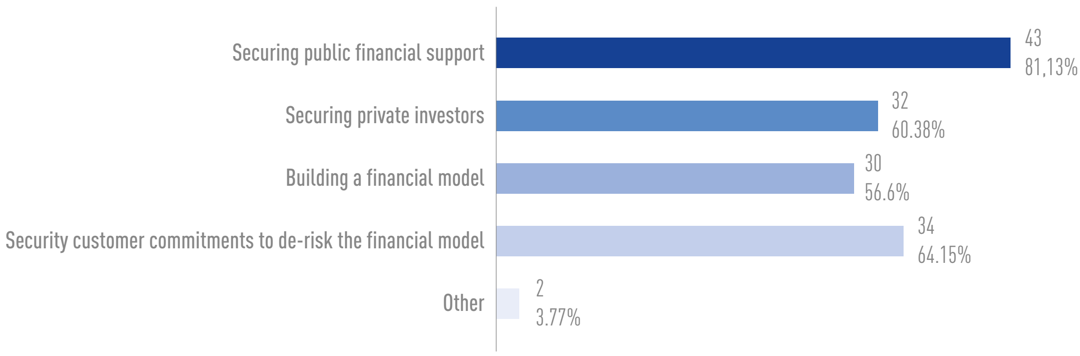


Source: Hydrogen Valley Platform.

9.3. MAIN BARRIERS – PROJECT FINANCING

Financing commercial aspects of valleys is key to the success of the projects: the nascent hydrogen ecosystem will affect many different stakeholders and create a lot of new users. However, business cases do not always provide certainty and investors might be reluctant to commit. In many cases, building of a financial model has proven challenging for many projects. But securing public financial support and private investment is anticipated to be one of the main barriers, together with securing commitments of end-users to de-risk the financial model. Figure 20 shows how many valleys identify each one of the different sorts of impediments as critical for financing and commercialisation, and what share of all valleys consider them as key to the success of their project.

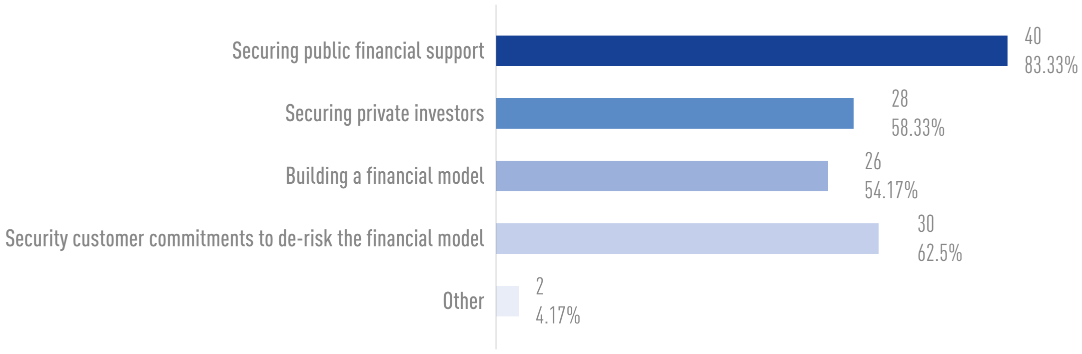
Figure 20: Main project financing barriers – global



Source: Hydrogen Valley Platform.

As shown in Figure 21, 83 % of the valleys located in Europe consider that public financial support will be necessary to de-risk the financial model and develop viable business cases. Since hydrogen markets and the necessary infrastructure are yet to be developed, incentives to facilitate final investment decisions will be necessary, together with all other missing elements.

Figure 21: Main project financing barriers – Europe



Source: Hydrogen Valley Platform.

10. INTERNATIONAL HYDROGEN ROLL-OUT

H2 production

The United States recently published its multi-year programme plan[72] with a roadmap of KPIs to be achieved within the next decade along with the current (2022) status of the technology. It focuses on certain targets with respect to CAPEX, degradation, lifetime and electrical consumption. In 2021, China also published, for the first time, a medium- to long-term plan for the development of the hydrogen energy industry up to 2035[73]. However, it does not mention specific values as targets. Japan – historically the first country to have developed a national hydrogen strategy, in 2017 – has also published and updated its KPI targets over the years[74].

Compared to the global situation, there is a trend in Europe of hydrogen production technologies and projects achieving lower electrical consumption but with higher CAPEX. This trend is reflected in the KPIs, since the United States and international associations such as the International Energy Agency consistently set targets that are more ambitious than those in Europe.

H2 transport – liquid hydrogen carriers

Internationally, the LOHC delivery chain has been demonstrated at large scale in a project transporting hydrogen from Brunei to Japan: the Japanese SPERA Hydrogen project[75]. In June 2020, the SPERA Hydrogen demonstration was successfully concluded with the transport of toluene from Japan to Brunei, where it was recombined with hydrogen to form methyl cyclohexane. This was the world's first international hydrogen delivery.

In Europe, the Port of Rotterdam, together with several partners, carried out a feasibility study on large-scale import of hydrogen. In recent years, Hydrogenious[76] signed memoranda of understanding with renewable energy development companies for joint feasibility studies that will explore the transport chain of hydrogen from North Africa and the Middle East to Europe using LOHC technology. At the same time, it signed a memorandum of understanding with the Port of Amsterdam to develop large-scale hydrogen import facilities at the port. Delivery to off-takers is scheduled from 2028. At the same time, HE will fund a project (Ship-aH2oy[77]) to develop and demonstrate a zero-emission propulsion technology on board ships using green hydrogen from Hydrogenious' LOHC technology at megawatt scale. Finally, the Green Hydrogen@Blue Danube by Hydrogenious[78] has been officially designated by the European Commission as one of the Important Projects of Common European Interest (IPCEI).

H2 refuelling stations

The deployment of HRSs is expanding globally. In 2023, 85 new HRSs went into operation worldwide: 37 were opened in Europe, 41 in Asia and 7 in North America. As in 2021 and 2022, South Korea was the country adding

72 https://www.energy.gov/eere/fuelcells/hydrogen-and-fuel-cell-technologies-office-multi-year-program-plan?utm_medium=email&utm_source=govdelivery

73 https://www.ndrc.gov.cn/xxgk/zcfb/ghwb/202203/t20220323_1320038.html?code=&state=123

74 https://www.meti.go.jp/shingikai/enecho/shoene_shinene/suiso_seisaku/pdf/20230606_5.pdf

75 https://www.chiyodacorp.com/en/service/spera-hydrogen/

76 https://hydrogenious.net/

77 H2 tech – Horizon Europe funds maritime onboard application for Ship-aH2oy project

78 https://hydrogenious.net/ipcei-hydrogenious-lohc-receives-multi-million-grant-for-green-hydrogen-blue-danube/

the largest number of new stations[79]. The number of HRSs in the EU is increasing, although at different rates in different Member States. The EHO reported a total of 178 HRSs at the end of May 2023. Of the 178 HRSs, 159 offer operation at 70 MPa for the refuelling of FC passenger cars, 54 are able to operate at 35 MPa for the refuelling of FC passenger cars and 35 offer 35 MPa refuelling for FC buses.

The Clean Hydrogen JU has funded the installation of 113 HRSs to date, including for car, bus and MHV demonstration projects. The technological progress on HRSs reported here has been made by car and bus demonstration projects, which are reviewed under pillar 3.

Cars

According to recent data, the worldwide fleet of FCEVs (passenger cars) had surpassed 57 000 units by the end of 2022. The Asian region is leading the deployment of FCEVs with 65 % of the fleet, followed by North America (26 %) and Europe (9 %). At country level, South Korea is leading the deployment of FCEVs with 51 % of the worldwide fleet (29 337 FCEVs), followed by the United States (26 %, 14 979 FCEVs), Japan (13 %, 7 619 FCEVs) and Germany (4 %, 2 201 FCEVs). In Europe, Germany tops the charts (44.3 %), followed by France (11.8 %) and the Netherlands (11.6 %).

Heavy-duty vehicles

In term of deployment, Asia dominates the heavy-duty FCET sector, driven by China's 98 % share. Europe comes in second with 1.7 %, while North America has a 0.3 % share. Switzerland leads the European heavy-duty FCET market. This is due to the deployment of a fleet of 140 Hyundai Xcient trucks there. This fleet is expected to grow by another 1 600 trucks by 2025[80]. In the autumn of 2022, there were 47 trucks operating at 23 Swiss companies carrying out logistics, distribution and supermarket supply activities.

Buses

As of June 2023, there were around 7 000 FCEBs in operation worldwide, mostly in China, which accounts for over 85 % of global deployment[81]. Other regions such as Europe, Japan, South Korea and the United States are also developing FCEB fleets, although at a slower pace. By the end of 2022, South Korea (281) and the United States (211) followed China (5 410) in second and third place, respectively. Japan (124), the United Kingdom (98), Germany (68), India (58) and the Netherlands (54) are the other countries with more than 50 units. Other countries that also operate FCEBs are France (33), Austria (25), Switzerland and Italy (20 each). Belgium, Denmark, Spain, Latvia, Luxembourg, Norway, Portugal and Sweden are the remaining European countries that operate FCEBs, with 1-9 units each. Europe as a whole had 364 FCEBs in operation at the end of 2022, being the most active region in the deployment of hydrogen buses after China. In 2023, Germany witnessed a significant uptake of FCEBs, with notable stakeholders embracing this technology. For instance, Deutsche Bahn has approved the purchase of 60 FCEBs[82], while the cities of Weimar[83] and Frankfurt[84] have also shown their support for the vehicles. Similar developments are taking place in Liverpool, in the UK, where the first of 20 planned FCEBs was introduced in 2023[85]. Additionally, Higer, a Chinese manufacturer, is currently conducting trials for FCEBs in

79 https://www.h2stations.org/press-release-2024-europe-is-increasingly-adapting-its-growing-hydrogen-refuelling-infrastructure-to-include-heavy-duty-vehicle-refuelling/

80 https://fuelcellsworks.com/news/fleet-of-hyundai-xcient-fuel-cell-trucks-surpass1-million-kilometer-benchmark-in-switzerland/

81 https://www.ieafuelcell.com/fileadmin/publications/2023/2023_Deployment_of_Fuel_Cell_Vehicles_and_Hydrogen_Refueling_Station.pdf

82 https://fuelcellsworks.com/news/deutsche-bahn-approves-purchase-of-60-hydrogen-buses/?mc_cid=bcc521eb55&mc_eid=da4624d261

83 https://fuelcellsworks.com/news/weimar-becomes-first-city-with-hydrogen-buses-in-thuringia/?mc_cid=850deae301&mc_eid=da4624d261

84 https://www.hydrogenfuelnews.com/hydrogen-buses-icb-solaris/8558799/#:~:text=The German metropolis has ordered,ICB fleet in Q1 2024

85 https://www.h2-view.com/story/hydrogen-buses-enter-passenger-service-in-liverpool/

Brazil and Uruguay[86]. Notably, South Korea has made substantial strides in this area, with plans to deploy 700 FCEBs in Incheon by the end of 2024[87] and 1 300 in Seoul by 2030[88], partly supported by a subsidy programme[89] (Fuel Cell Works, 2023).

The technical specifications of the buses (FC power capability, storage capacity, range and hydrogen consumption) have clearly improved worldwide over the last few years. China is still the leading manufacturer of FCEBs. The European countries follow in terms of numbers of FCEB manufacturers and indicators of technological progress and innovation[90]. This is partly due to the significant contribution of Clean Hydrogen JU demo projects (CHIC, HIGH V.LO-CITY, HYTRANSIT, 3EMOTION, JIVE and JIVE 2)[91], focusing on the large-scale demonstration of FCEBs in Europe since 2010.

Rail applications

Hydrogen and FC technology for rail applications has been trialled across Europe, Asia, North America, the Middle East, Africa and the Caribbean since 2005[92]. Although the trials show that FC and hydrogen technologies can meet the requirements for rail applications, there are few demonstration projects of hydrogen train prototypes.

Hydrogen valleys

The Infrastructure Investment and Jobs Act of 2021 in the United States authorised the Department of Energy to spend USD 8 billion on establishing regional clean hydrogen hubs. This programme aims to provide a foundation for reducing the cost of clean hydrogen production and establishing a domestic clean hydrogen industry. The initiative has garnered substantial interest, and in October 2023, seven regional hubs located across the US were chosen for funding. Five hubs are based on blue hydrogen and three hubs on nuclear-based hydrogen production. The hubs are deploying hydrogen across a broad spectrum of end-use sectors, as required by law, including heavy-duty transport and ammonia production[93]. A recently announced demand-side initiative with funding of up to USD 1 billion[94] complements the hydrogen hubs.

In Australia, the largest hydrogen valley project in the Eyre Peninsula is focused on green ammonia production. There are three planned Chinese projects (one operational) which seem to be centred around mobility end-uses. A feasibility study is ongoing in Chile for utilising on-shore wind power to produce green hydrogen to use for mobility and as industrial feedstock.

86 https://fuelcellsworks.com/news/higer-will-have-an-articulated-electric-bus-running-in-brazil-and-uruguay-by-july/?mc_cid=762126b762&mc_eid=da4624d261

87 https://fuelcellsworks.com/news/in-2023-korea-will-provide-16920-hydrogen-vehicles-with-subsidies-of-30m-won-24-4m/?mc_cid=49fd008c93&mc_eid=da4624d261

88 https://www.hydrogeninsight.com/transport/south-korean-capital-city-signs-deal-for-1-300-new-hydrogen-buses-by-2026-says-hyundai/2-1-1463347

89 https://fuelcellsworks.com/news/in-2023-korea-will-provide-16920-hydrogen-vehicles-with-subsidies-of-30m-won-24-4m/?mc_cid=49fd008c93&mc_eid=da4624d261

90 https://fuelcellbuses.eu/suppliers#29

91 https://fuelcellbuses.eu/

92 Study on the use of fuel cells and hydrogen in the railway environment, FCH 2 JU, 2019.

93 https://www.catf.us/2023/10/moving-application-action-priority-focus-areas-does-regional-clean-hydrogen-hubs/

94 https://www.energy.gov/oced/articles/us-department-energy-seeks-independent-entity-new-demand-side-initiative-accelerate

11. EUROPEAN HYDROGEN LANDSCAPE: 2023 OVERVIEW

The European Hydrogen Observatory (EHO or Observatory)[95], one of the most prominent initiatives of the Clean Hydrogen JU, provides an overview of technology and market statistics, socio-economic indicators, policies and regulations, and financial support. Its purpose is to allow monitoring of the deployment of hydrogen technologies, the adoption of related policies, academic activities and research results. It is an open platform providing data and up-to-date information about the European hydrogen sector (EU-27, EFTA and the UK). The EHO was created to benefit policymakers, industry stakeholders and the general public equally and is the main public portal for European hydrogen data. Inaugurated in 2018 (as the Fuel Cells and Hydrogen Observatory), it was officially relaunched in September 2023 under its new branding. It has seen a steady increase in numbers of visitors since then, indicating that it is recognised as an important source of information on hydrogen. The Observatory continuously updates the information it provides, trying also to expand with additional datasets and key information for hydrogen sector stakeholders. Figure 22 presents an overview of the hydrogen landscape at the end of 2023, based on the available datasets.

Hydrogen production capacity was approximately 11.2 million tonnes, with the vast majority (95.9 %) using conventional production methods (reforming, partial oxidisation, gasification and by-product production from refining and ethylene/styrene). The capacity of water electrolysis projects in operation has increased significantly the last years, from 99 MW in 2020 to 258 MW in 2023 (+160 %). A significant share (87 %) of the total hydrogen production capacity in Europe is dedicated to on-site captive consumption, indicating that it is primarily produced and used within the facility, with the rest specifically allocated for external distribution and sale. This is known as merchant consumption. When looking at the expected capacity increase of water electrolysis projects that are currently under construction, an even higher increase should follow in the coming years, reaching 1 857 MW by 2025[96].

European electrolyser manufacturers are expected to reach a capacity of 10.48 gigawatts (GW)/year[97] by 2026, of which 45 % will be PEMEL manufacturing capacity, 44 % will be AEL, 8 % will be SOEL and 3 % will be AEMEL. As of May 2024, 5.40 GW/year of operational capacity is already operational[98]. In 2023, European manufacturers sold water electrolysers with a total capacity of approximately 65 MW, with Alkaline technologies making up 43 % of total sales. The cost of the technology is also important: in 2023, the total AEL CAPEX in Europe was EUR 1 666/kW, which is split between EUR 408/kW for the stack, EUR 686/kW for BoP and EUR 572/kW for other EPC, while OPEX amounted to EUR 42.5/kW/year. For PEMEL, in 2023 the total CAPEX in Europe was EUR 1 970/kW, which is split between EUR 732/kW for the stack, EUR 464/kW for BoP and EUR 774/kW for other EPC, while the OPEX was EUR 63.5/kW/year[99].

Hydrogen consumption in Europe has been estimated at approximately 8.23 Mt, reflecting an average capacity utilisation rate of 73 %. The biggest share of hydrogen demand comes from refineries, which are responsible for 57 % of total hydrogen use (4.5 Mt), followed by the ammonia industry with 25 % (2.0 Mt)[100].

95 https://observatory.clean-hydrogen.europa.eu/homepage

96 https://observatory.clean-hydrogen.europa.eu/hydrogen-landscape/production-trade-and-cost/hydrogen-production

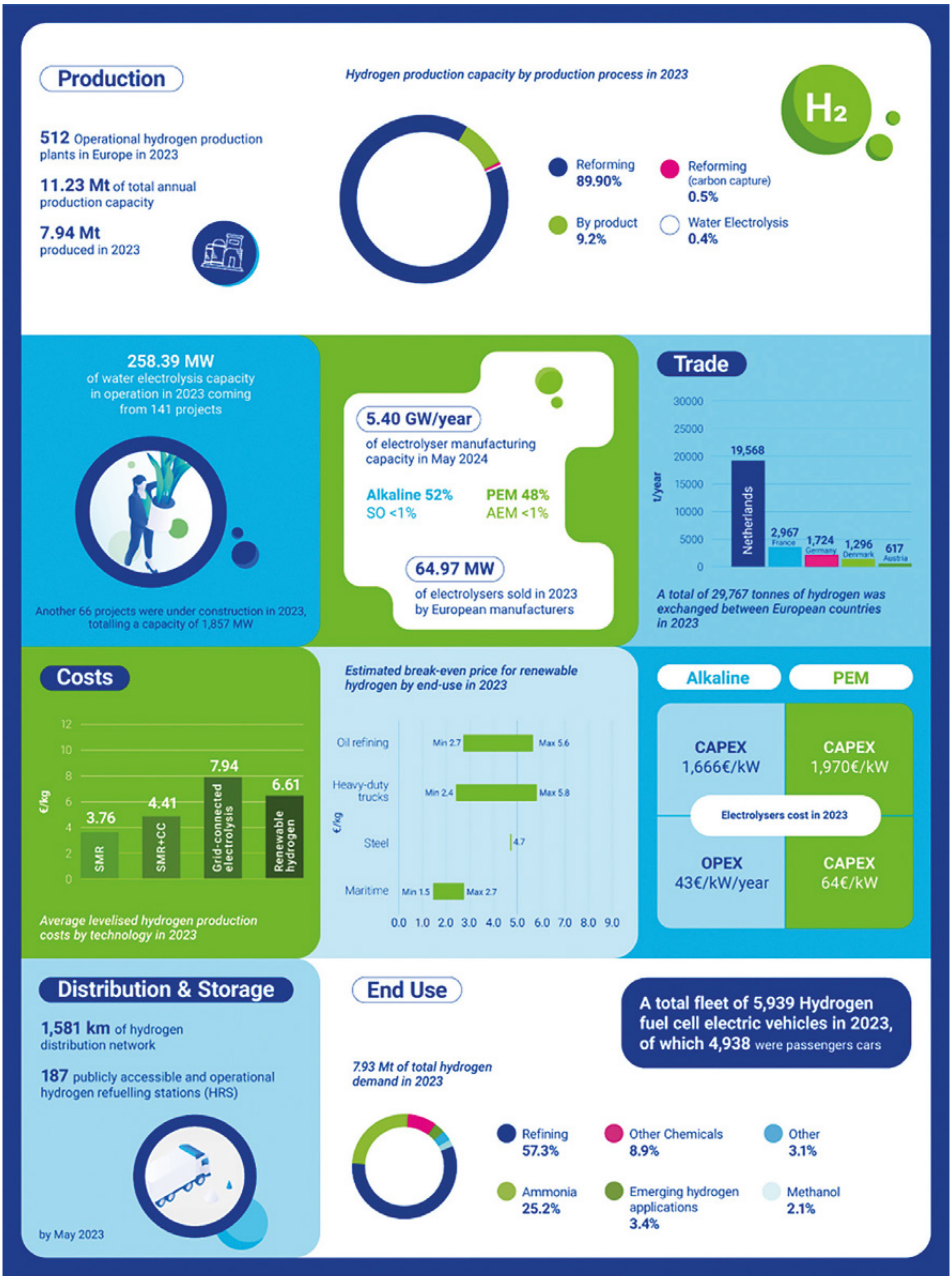
97 Only projects already under construction or with a final investment decision are included.

98 https://observatory.clean-hydrogen.europa.eu/hydrogen-landscape/technology-manufacturing/electrolyser-manufacturing-capacity

99 https://observatory.clean-hydrogen.europa.eu/hydrogen-landscape/production-trade-and-cost/electrolyser-cost

100 https://observatory.clean-hydrogen.europa.eu/hydrogen-landscape/end-use/hydrogen-demand

Figure 22: Key insights into the hydrogen landscape



Source: European Hydrogen Observatory.

Clean hydrogen consumption was about 20 kilotonnes in Europe in 2023, less than 0.25 % of the total hydrogen demand. Clean hydrogen consumption mainly served new emerging applications, such as mobility, blending with NG in pipelines and production of steel. As for mobility, the number of FCEVs is constantly growing, reaching 5 939 in 2023[101]. To meet this hydrogen demand, the number of operational and publicly accessible HRSs also increased, reaching 187 by July 2024[102].

In 2023, the LCOH of renewable hydrogen, although slightly reduced to 6.61 €/kg H2 compared from 6,86 €/kg H in 2022, lost its competitiveness towards SMR that was observed in 2022. This due to the sharp decrease of the energy prices, reducing the LCOH of SMR from 6,23 €/kg H_2 in 2022 to 3.76 €/kg H_2 in 2023, close to its 2021 value (2.67 €/kg H_2)[103]. When looking at the breakeven prices of renewable hydrogen for different end-uses, there is a diverging trend compared to previous years, with a reduction in the oil refining industry, but increase in the steel making and maritime applications[104]. A LCOH calculator for water electrolysis is available at the EHO[105] to allow more in-depth analysis of potential hydrogen production cases.

The EHO database includes 29 EU policies and pieces of legislation that directly or indirectly affect the development and deployment of hydrogen technologies. The EU started with cross-cutting strategies, such as the European Green Deal and the EU hydrogen strategy, setting out roadmaps and targets to achieve. These were made concrete though legislation consolidated in the Fit for 55 package. At national level, two thirds of European countries have successfully published their national strategies for the hydrogen sector. Germany took the lead on electrolysis capacity with an ambitious goal of achieving 10 GW by 2030, followed by France (6.5 GW) and Denmark (4-6 GW), while other targets refer to numbers of HRSs, FCEVs and total (renewable) hydrogen demand, renewable hydrogen uptake in industry and hydrogen injection limits in the transmission grid. National policies are being monitored through a survey with the participation of 30 European countries. On the development of renewable or low-carbon hydrogen production plants, 19 countries provide support for CAPEX and 7 countries for OPEX. For transmission, only two countries reported that they provide support schemes for hydrogen injection, while several have set hydrogen limits in their transmission grid for now and in the future, ranging from 0.02 % to 15 %. Regarding end-uses, 71 % of the countries reported having implemented support schemes to promote the adoption of hydrogen in the mobility sector. For hydrogen end-use in industry, a total of 9 countries reported that they provide support schemes with a major focus on ammonia production (8 countries) and the chemicals industry (7 countries)[106].

101 https://observatory.clean-hydrogen.europa.eu/hydrogen-landscape/end-use

102 https://observatory.clean-hydrogen.europa.eu/hydrogen-landscape/distribution-and-storage/hydrogen-refuelling-stations

103 https://observatory.clean-hydrogen.europa.eu/hydrogen-landscape/production-trade-and-cost/cost-hydrogen-production

104 https://observatory.clean-hydrogen.europa.eu/hydrogen-landscape/end-use/break-even-price-of-renewable-hydrogen

105 https://observatory.clean-hydrogen.europa.eu/tools-reports/levelised-cost-hydrogen-calculator

106 https://observatory.clean-hydrogen.europa.eu/hydrogen-landscape/policies-and-standards

12. CONCLUSIONS AND NEXT STEPS

Decarbonising the EU's energy system is critical to reach our 2030 climate objectives and the EU's long-term goal of achieving carbon neutrality by 2050. Clean hydrogen can contribute to decarbonising the hard-to-abate sectors: not only energy-intensive industries (such as steel, chemicals and cement) and the transport sector (e.g. HDVs, rail and maritime), but also the power sector.

Substantial efforts are being made to establish a solid basis for advancing technological performance in electrolysis, in particular in the areas of PEMEL and SOEL, to enable renewable hydrogen production at mass scale. The programme must also continue to support PCCEL and AEMEL technologies, as these may have advantages for some applications. Focus will be maintained on areas of added value, including selected demonstrations that can assist with rapid embedding in industrial settings. Cooperation with other initiatives' projects (Connect Europe Facility, Innovation Fund) and IPCEI projects could be beneficial in this sense, in order to achieve joint collaborations (design requirements, testing protocols, materials use and sourcing, prototype testing, etc.) and dissemination, particularly to value chain actors and stakeholders.

The Clean Hydrogen JU has successfully supported innovative technological storage and distribution solutions, such as those for large-scale storage like solid-state hydrogen storage. Also, the demonstration of a salt cavern working with renewable hydrogen will validate renewable-based hydrogen value chains, including future hydrogen valleys with available caverns/gas fields. Synergies between projects are expected to play a vital role, in particular in regulatory and standardisation progress in this area. Also, aside from the LCOH solutions already investigated, innovative solutions for liquid hydrogen storage and liquefaction are being developed for the first time. Hydrogen in NG should also be a priority, especially focusing on high-strategic-value 100 % hydrogen testing.

In transport, a number of technology routes still need further improvements, especially in the context of reducing costs and increasing durability, in order to make them competitive with incumbent technologies: HDVs, off-road and industrial vehicles, trains, shipping and aviation. PEMFC systems with satisfactory performance for transport and stationary applications are already available, but additional effort is necessary to understand the degradation mechanisms and improve durability. The use of expensive and rare materials, especially PGMs, to ensure reliable performance and satisfactory durability must be addressed to allow broader application of PEMFC technology.

The heat-and-power demonstration projects focused on remote locations and back-up power generation can serve as valuable foundations for future initiatives. Despite the progress made in both stationary PEMFCs and SOFCs so far, further advancements are needed to meet KPI targets like durability and reliability, maintenance cost and land use footprint. Stationary FCs can play a crucial role in security of supply under exceptional circumstances, such as natural disasters, as well as in the context of global instability and geopolitical unrest. The lessons learned from existing projects can be applied to enhance the development and deployment of stationary FCs in these critical applications.

The methodologies to assess the environmental impact of hydrogen production need to be harmonised with the current methodologies proposed in EU policies (e.g. RED II, Taxonomy, CBAM). The European Hydrogen Sustainability and Circularity Panel should put in place a structure to monitor and assess the sustainability activities of the projects. It could also create a benchmark for the environmental impact of the different hydrogen technologies. Also, additional efforts to close the gap identified in education and training are necessary.

Further attention must be dedicated to RCS and PNR for handling (storage, transport, delivery) large quantities of hydrogen, both in its compressed and liquid state. Projects dealing with large hydrogen quantities can deliver the knowledge and the data required to fully understand large transfer phenomena and risks.

The development of a vice-versa sharing and spill-over mechanism will enrich the Clean Hydrogen JU's own PNR and RCS activities, if confidentiality issues are adequately addressed.

Ambitions for hydrogen valleys remain high but the end-users' commitment to ensure the necessary co-funding for full deployment is not guaranteed; coordination efforts are needed to support combinations of EU and national/regional funding to reduce remaining funding needs, so that these can, at least in large part, be borne by industry partners. Additional coordination is also needed in developing digital tools to support replicability. To address this, the Clean Hydrogen JU recently launched a tender to set up and run a Hydrogen Valleys Facility[107], aiming to accelerate growth in the number of hydrogen valleys in Europe. The facility will include PDA to support hydrogen valleys at different levels of maturity. Another potential bottleneck for hydrogen valley stakeholders is related to training and education; it is recommended that any investments related to the deployment of hydrogen valleys be accompanied by investment in human capital.

The main segments of the supply chain must be covered by European manufacturers, including the production of specialised/advanced materials, components and equipment. Additional effort needs to be invested in developing adequate tools/machines/robots for automation of the manufacturing processes, which will bring cost reductions.

Management of the accumulated knowledge and data is becoming critical. The Hydrogen Knowledge Hub will improve the data collection interface and visualisation of data. It will collect and manage the knowledge produced by the Clean Hydrogen JU programme and its projects by coordinating access to non-confidential information for stakeholders, the scientific community and society in general. The Knowledge Hub must be open to the whole hydrogen value chain in Europe, collecting data from R&I projects and large demonstrations, including European, regional and local projects, and act as a single data repository for hydrogen applications.

Overall, it is widely accepted that the Clean Hydrogen JU activities have been aligned quickly and successfully with recent R&I policy priorities as expressed in the Green Deal and REPowerEU. Although many projects reviewed were designed under the H2020 programme of the FCH 2 JU, they clearly reflect the expected increase in attention to renewable hydrogen production, selected end-use sectors and the supply chain. The programme therefore demonstrates structural flexibility and the capacity to align quickly with European Commission policy requirements for the whole of its implementation period.

107 https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/tender-details/424246ca-5b16-41b0-8bd0-355c769a396a-CN

ANNEX: PROJECT REVIEW AND POSTERS

I. PILLAR 1 – RENEWABLE HYDROGEN PRODUCTION

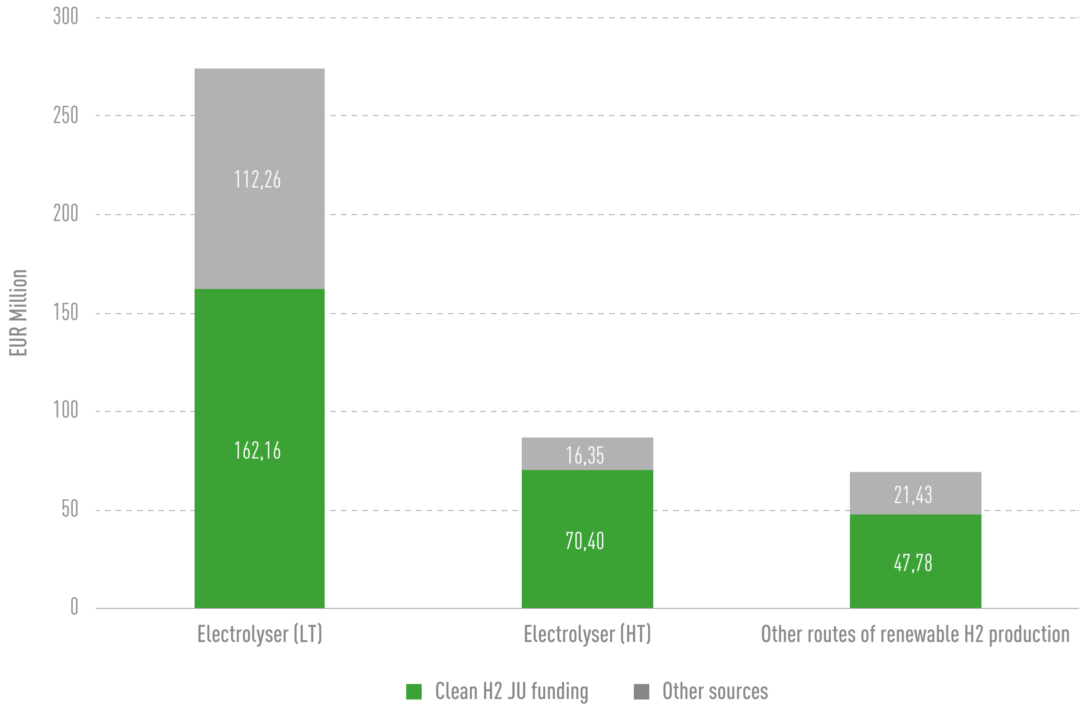
OBJECTIVES: In a short time span of 6 years, the significant increase in the number of funded electrolysis projects, from 29 (up to the 2017 calls) to 61 (up to the 2023 calls) in total, and the fact that the cumulative funding for both LT and HT electrolysis technologies increased by almost 2.5 times demonstrates the importance of EU support to R&D for these two electrolysis technologies.

For pillar 1, three research areas were defined for this year's assessment:

- LT electrolysis: this includes AEL, PEMEL and AEMEL;
- HT electrolysis (including co-electrolysis): this includes SOEL and PCCEL;
- other hydrogen generation methods (thermo-chemical hydrogen generation).

OPERATIONAL BUDGET: The Clean Hydrogen JU supported 78 projects relevant to this pillar between 2008 and 2023, with a total Clean Hydrogen JU contribution of EUR 280.34 million and a contribution from partners of EUR 150.8 million. The distribution of funding over the three research areas considered in this pillar is shown in Figure 23. The overall funding for LT electrolysis projects is around 57 %, for HT electrolysis projects around 26 % and for projects in other routes of renewable hydrogen production about 17 %.

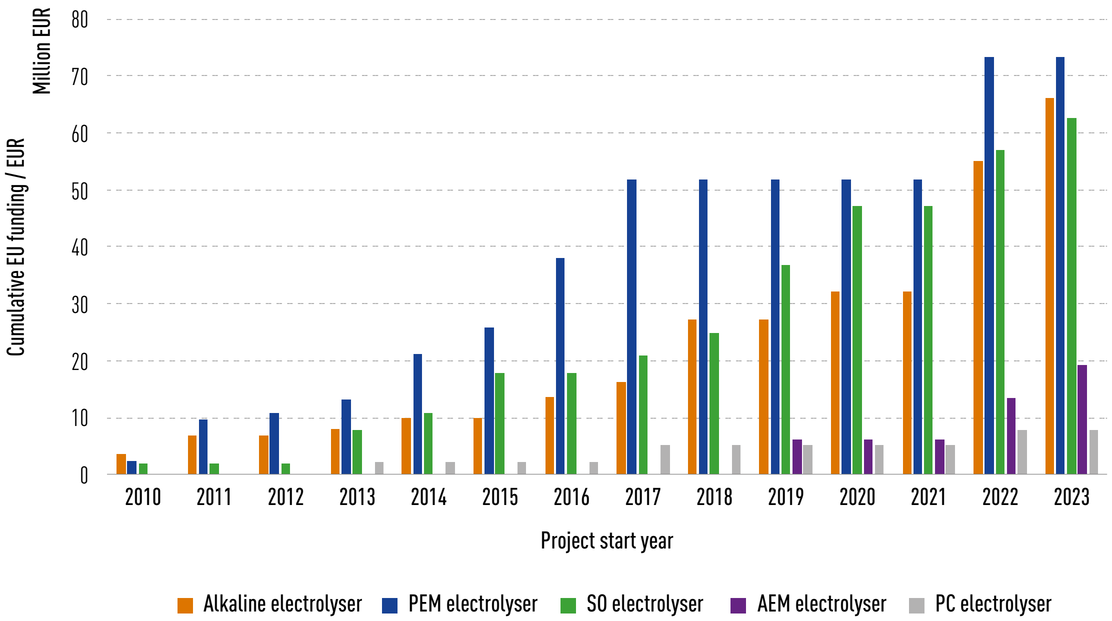
Figure 23: Funding for pillar 1 projects from 2008 to 2023



Source: Clean Hydrogen JU.

Figure 24 shows the cumulative contribution to projects working on various electrolyser technologies from 2010 onwards. PEMs and AEL have received the highest shares of the funding, but support for SOEL development is increasing steadily and could reach similar levels in the future, should this trend continue.

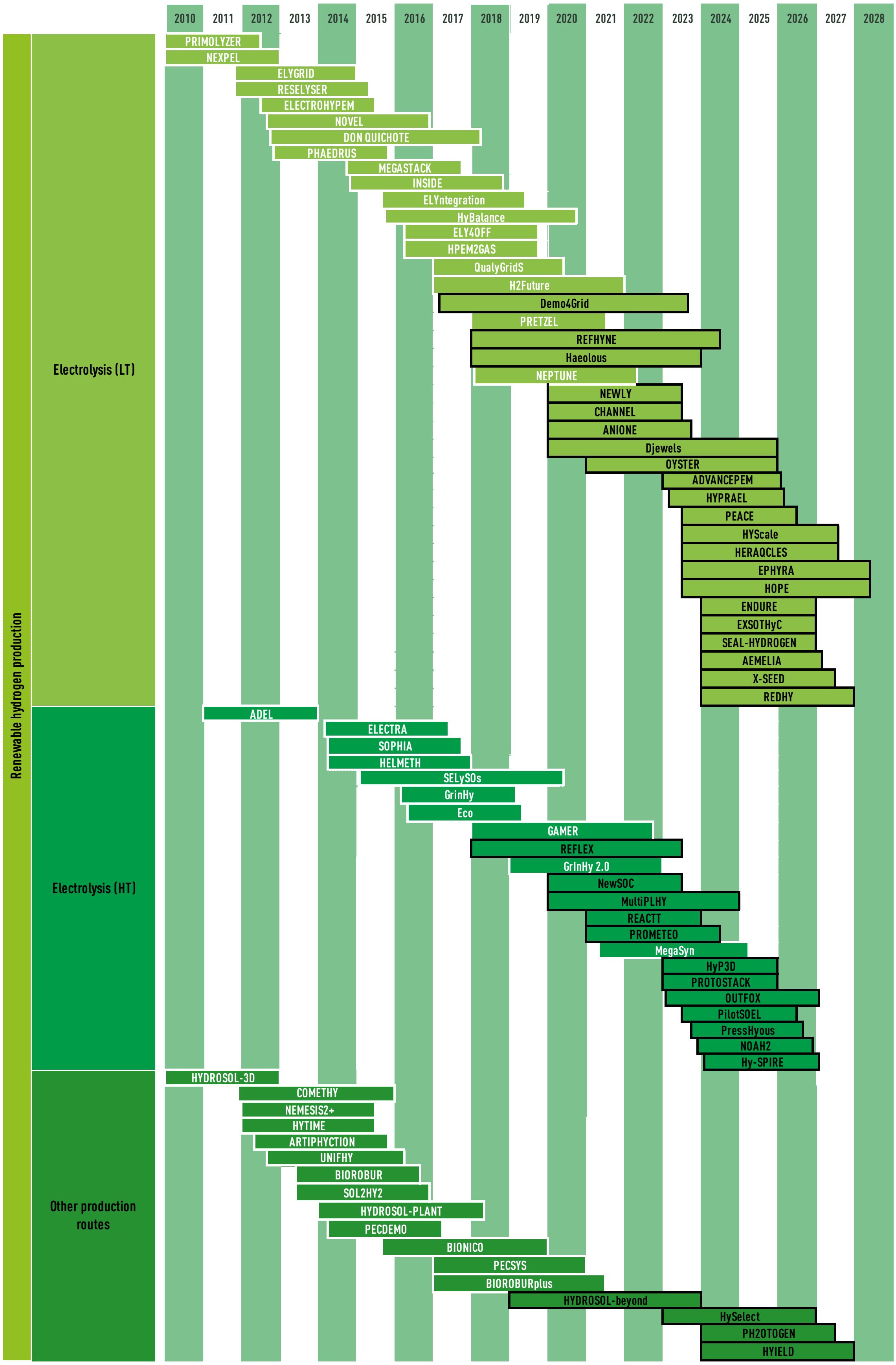
Figure 24: Cumulative level of EU funding contribution for projects related to different electrolysers



Source: Clean Hydrogen JU.

PROJECTS IN BRIEF: The projects are mainly devoted to the development and demonstration of LT and HT electrolysis. The 37 pillar 1 projects reviewed in the document are listed and highlighted in black in Figure 25.

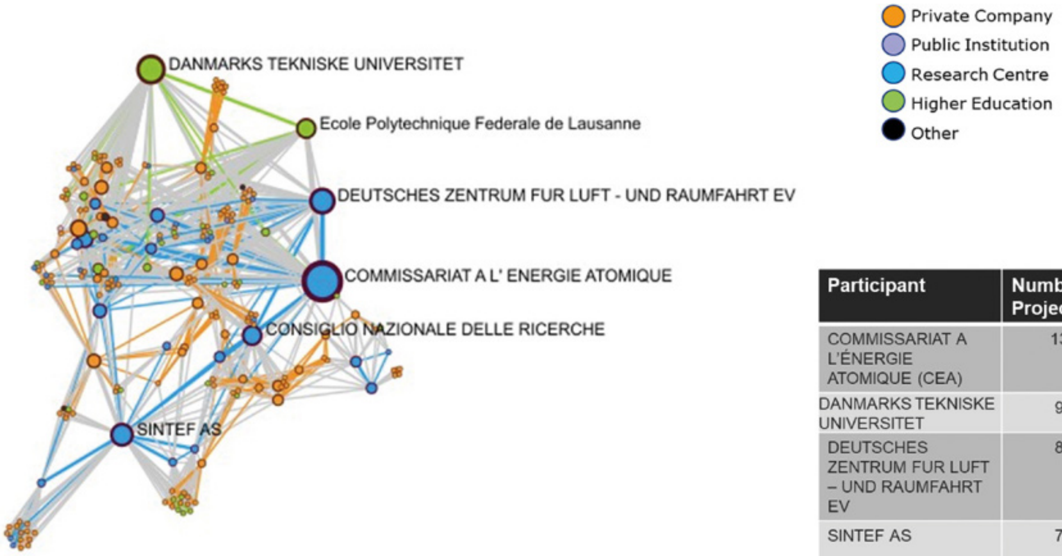
Figure 25: Project timelines for pillar 1 – renewable hydrogen production



Source: Clean Hydrogen JU.

Many of the participants in the projects grouped under pillar 1 have strong links to each other. The key participants in this panel (i.e. those present in the most projects) are primarily research institutes (CEA, DTU, DLR and SINTEF). Figure 26 shows the connections between partners in the projects reviewed. The size of the node (circle) is related to the number of projects a partner is involved in, whereas the thickness of the lines linking the nodes is related to the number of projects two partners have in common. The colour is based on the type of organisation as provided in CORDIS.

Figure 26: TIM plot showing the participants in the 37 projects in pillar 1

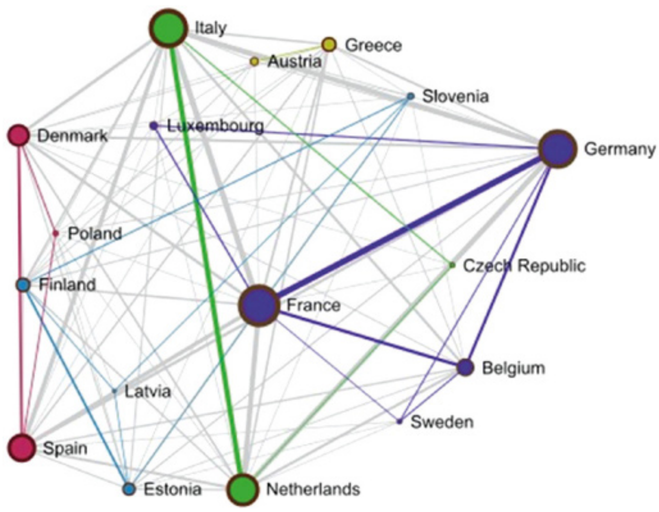


Participant	Number of Projects
COMMISSARIAT A L'ÉNERGIE ATOMIQUE (CEA)	13
DANMARKS TEKNISKE UNIVERSITET	9
DEUTSCHES ZENTRUM FUR LUFT – UND RAUMFAHRT EV	8
SINTEF AS	7

Source: TIM, JRC, 2024.

Figure 6 shows the geographical distribution (of EU Member States) of the participants that are active in this year's Pillar 1 project portfolio. In this case, the nodes represent the number of projects that have at least one partner from that country. The thickness of the links represents how many projects particular countries have in common. In terms of Member State participation, France, Germany, Italy, the Netherlands, Denmark and Spain are involved in the most projects within Pillar 1. The key participants in this panel are dominated by respective research institutes that are located in the named countries.

Figure 27: TIM plot showing EU Member State participation in pillar 1 projects



Member State	Number of Projects
France	26
Italy	24
Germany	24
Netherlands	20
Spain	17

Source: TIM, JRC, 2024.

The JRC performed an historical analysis to show how projects within the first two programmes (FCH JU and FCH 2 JU) contributed to the achievement of the MAWP KPI targets for the three highest TRL electrolyser technologies (AEL, PEMEL and SOEL). For the energy demand KPI, an update of this historical data follows.

Low-temperature electrolysis projects

The focus area currently consists of 21 projects, including 10 on AEL (DEMO4GRID, DJEWELS, OYSTER, EPHYRA, HYPRAEL, PEACE, ENDURE, EXSOTHyC, SEAL-HYDROGEN, X-SEED), 4 on PEM electrolysis (REFHYNE, HAEOLUS, ADVANCEPEM, HOPE) and 7 on AEM electrolysis (ANIONE, CHANNEL, NEWELY, HYScale, HERAQCLES, AEMELIA, REDHy). Several of these projects are at a relatively early stage. Many projects are looking closely at LCA, health, safety and environmental aspects.

Alkaline electrolysis projects

DEMO4GRID featured the demo operations of a 3.2 MW pressurised AEL situated within the MPREIS industrial bakery premises. A power usage of 51 kWh/kg H_2 for the electrolyser is reported, narrowly missing the SRIA 2024 benchmark of 49 kWh/kg H_2. It efficiently generates 53 kg H_2/h at 31 bar, with a purity level of 99.8 %. MPREIS replicated the creation of a small hydrogen valley, creating a synergetic system within the electrolyser providing hydrogen, storage tanks infrastructure, HRSs and hydrogen trucks. Furthermore, the hydrogen production and storage can be tuned to balance with the daily energy production and demand of a local hydro power plant. The grid stabilisation service will, therefore, increase profitability. To establish a stable hydrogen economy in the Tyrol region, MPREIS established a connection with two other hydrogen producers: ZVB/Verbund and TIWAG Power2X.

DJEWELS plans to deploy a high-current-density AEL at 20 MW scale. The electrolyser system should be able to operate flexibly at 20-100 % of nominal power at a low degradation rate of less than 1 %/year and a system energy consumption rate of less than 52.9 kW/kg H_2, which would be a significant contribution to reaching the MAWP 2024 targets. Furthermore, the 1 MW pilot test incorporates new high-current electrodes (0.9 A/cm^2). Still, technical challenges remain, with a high degradation rate for electrolyser components due to the high operating current density target for this technology.

EPHYRA aims to develop a technology and integration concept for an innovative AEL system (30 MW capacity) with the largest single stack in industry (5-10 MW). Oxygen and waste heat streams will also be valorised and optimised. Operation of the plant will guarantee the attainment of the SRIA targets with an LCOH of EUR 3.3/kg. A techno-economic, environmental and societal sustainability study is expected to help to develop an economic case for the integration of the plant into industrial assets.

HYPRAEL aims to provide pressurised H_2 at ≥ 80 bar using a power stack ≥ 50 kW which is operated at 120°C-150 °C. This technology benefits downstream processes such as gas grid injection or use of H_2 as feedstock for methanol synthesis, reducing energy costs when supplied with pressurised H_2. So far, one presented key deliverable is a report on selected functional materials and combination strategies to strengthen the membrane in AEL for elevated operating conditions.

PEACE develops and demonstrates an AEL system of > 50 kW, capable of operating at up to 90 bar thanks to a two-stage compression process (60 bar for an external pressure vessel and an additional 30 bar in the stack). The AEL system targets an efficiency level of 70 % (LHV) at a current density of 1 A/cm^2 in high-KOH-concentration feedstock at 80 °C (and up to 110 °C) for 500 hours with a degradation rate of 0.11 % per 1 000 hours. The project will also investigate the integration of the technology in industrial processes such as methanol synthesis, Fischer-Tropsch[108] or hydrocracking. The project targets capital costs per system of EUR 400/kW, calculated on a 100 MW production volume for a single company.

ENDURE aims to strengthen the durability of AEL with low degradation rates and increased efficiencies. To achieve these high-level goals, a porous transport-optimised electrode is developed and tested. Together with

108 The Fischer–Tropsch process converts syngas (a mixture of hydrogen and carbon monoxide) into liquid hydrocarbons through various chemical reactions.

the planned development of a PGM-free catalyst coating, a 10 kW prototype stack will be built at low cost. The stack will be validated and tested, including by recording a degradation profile of the prototype and comparing it to the benchmark.

EXSOTHyC will focus on the optimisation of alkaline electrolyser operation. The innovation pathway will firstly explore alternative pathways for O_2 and H_2 evolution reactions through new anode and cathode approaches. These electrodes will be integrated into novel MEA concepts, and finally a novel cell design will be presented. To achieve the innovation steps, novel perovskite powders including nanoparticles are developed to be used on a dimensionally stable electrode a few cm^2 in scale. The novelty in the approach is the introduction of a catalyst-coated diaphragm.

SEAL-HYDROGEN targets the development of an efficient and highly durable AEL stack competing with classic AEMEL and PEMEL, with CRM-free, layered, double-hydroxide catalytic materials combined with porous transport electrodes. The stack will be optimised by exploring novel three-electrode-cell designs characterised by cell performance and stability measurements. The project primarily aims at addressing the issue of low stability, avoiding the usage of CRMs and PFAS components.

X-SEED focuses on extreme operating conditions for a membrane-free AEL. The operation temperature is expected to be brought to ≥ 374 °C and operation pressure can exceed 220 bar. Nanostructured catalysts will be used to withstand these conditions and maximise efficiency. Furthermore, H_2 is produced pressurised with ~200 bar, lowering downstream process costs.

The **OYSTER** project has changed its scope from marinisation of a PEM electrolyser to marinisation of an AEL and is therefore included in this section. It aims to develop and demonstrate an electrolyser suitable for fully integrated deployment with an offshore wind turbine, based on a shore-side pilot project. The electrolyser needs to withstand a range of conditions such as high salinity, periods with no electricity generation, accelerations and deformations (physical motion of the offshore platform) and transportation to the site of use.

Proton exchange membrane electrolysis projects

REFHYNE has installed and is trying to operate a 10 MW PEM electrolyser manufactured by ITM and supply hydrogen to the Shell Rhineland Refinery in Wesseling, Germany. The electrolyser system is complete and fully integrated into the control system of the refinery process plant. By the end of 2022, the plant had run for approximately 1 200 hours and had produced more than 21 tonnes of hydrogen. The project has contributed an assessment on policy implications and has performed a detailed design study for a 100 MW electrolyser (REFHYNE 2). The business case is based on the provision of balancing services and production of hydrogen. The project will gather data on market conditions during its operation.

HAEOLUS installed two 1.25 MW stack electrolysers north of the Arctic Circle in a remote region of Norway. Powered by a dedicated power line, the electrolysers operate directly within the Raggovidda wind farm, which, due to limitations in grid capacity, cannot undergo further expansion. The aim was to showcase various methods and computational strategies for energy storage, autonomous grid functioning and hydrogen production—all aimed at enhancing the system's technical and economic efficacy.

ADVANCEPEM aims to improve the efficiency of PEMEL by operation at elevated differential pressures (200 bar), a high temperature range (90-140 °C) and a nominal operating current density of up to 5 A per cm^2. It focuses on energy savings for downstream processes thanks to lower compression needs and higher reaction rates. Moreover, the scope of the project includes characterisation of components at cell, stack and system level, usage and development of harmonised testing procedures for performance and durability assessment and safety aspects of the technology (already delivered).

HOPE aims to establish a 10 MW offshore hydrogen production system, integrated in a desalination system, to be installed on a barge 1 km off Ostend in Belgium. Technical feasibility will be proven by monitoring relevant system parameters like stack performance, degradation rate, etc. To achieve an operational lifetime of 20 years, innovative offshore utility and safety systems are developed. Furthermore, integration of the system into a supply chain with the help of an H_2 pipeline export will be explored as a first-of-its-kind action.

Anion exchange membrane electrolysis projects

CHANNEL aimed to develop a low-cost electrolyser stack and associated BoP, using low-cost materials, non-PGM catalysts, SoA anion exchange membranes and ionomers, along with low-cost transport layers, current collectors and bipolar plates to construct a 2 kW prototype stack. The project has developed active non-PGM hydrogen (HER) and oxygen (OER) evolution reaction catalysts for use in the 2 kW stack prototype. The single cell performance target of 1.85 V at 1 A/cm^2 using a non-PGM electro-catalyst has been achieved. The project also achieved its targets in terms of catalyst performance (reaching 237 mV overpotential at 1 M KOH and 270 mV at 0.1 M KOH with the OER catalyst, and 60 mV in 1 M KOH and 120 mV in 0.1 M KOH with the HER catalyst). Despite the difficulties in scaling up the performance at stack level, the project concludes, in its cost analysis study, that the objective of bringing the CAPEX below EUR 600/kW at a 500 kW system scale is achievable.

ANIONE has similar objectives. The project is developing non-CRM catalysts and novel membranes for application at TRL 4 for a validated 2 kW electrolyser. Two membranes for AEM water electrolysis have been developed. The first is a perfluorinated Aquivion-type backbone, reinforced with reasonable mechanical properties, low crossover and conductivity in the range of 50 mS/cm, which achieved promising performance of 0.9 A/cm^2 at 2.2 V at 90 °C with voltage efficiency approaching 70 %. The second is a highly conductive and chemically stable hydrocarbon ionomer/membrane with conductivity values above 100 mS/cm (higher than the benchmarked AEM membrane at 50 mS/cm), good chemical stability (< 10 % loss of ion exchange capacity after 2 000 hours in 1 M KOH at 80 °C), good mechanical strength and low crossover (< 1 % H_2 content in the oxygen stream during electrolysis operation). The project successfully produced large-area membranes (with an active area > 100 cm^2) and developed high-performance, electrochemically stable NiFe oxide oxygen evolution electrocatalysts. Twenty-five large-area MEAs (> 100 cm^2)[109] ready for stack assembly have been delivered, showing stability under 1 000 hours of cycled operations at 1 A per cm^2 with cell voltage close to 2 V/cell and sustaining several BoP interruptions[110].

NEWELY aimed to improve on responses to the three challenges of AEMEL: membrane, catalyst and stack performance and durability. The project successfully developed a poly(ethylene-ran-butylene)-block-polystyrene- and polybenzimidazole-based membrane with characteristics that successfully reached the project's targets (energy consumption at 53.6 kWh/kg @ 3.6 W/cm^2 corresponding to 2 V @ 1.8 A/cm^2, membrane conductivity at 62 mS/cm and area-specific resistance at 0.065 Ω cm^2) in 0.1 M KOH at 25 °C, lower than other AEM projects operating at 1 M KOH. The project submitted six publications and three patent applications, and a start-up was established to capitalise on the intellectual property acquired.

HYScale is dedicated to delivering a novel AEMEL technology at 60 °C with a current density of 2 A/cm^2 at ≤ 2 V/cell, pressure output at 15 bar and an enlarged active surface area (400 cm^2) with a nominal system power of 100 kW. The technology will be brought to TRL 5 with a targeted CAPEX of ≤ EUR 400/kW.

HERAQCLES is to develop new manufacturing approaches for novel electrolysis technology, with a proof of concept at 25 kW AEMEL and 30-50 bar operating pressure.

AEMELIA is undertaking the challenge of designing a prototype AEMEL that surpasses Hydrogen Europe's 2030 performance, durability, safety and cost targets. KPIs will be validated via a TRL 4 prototype of a five-cell stack at 100 cm^2, producing 7.2 Nm^3/day of H_2 at 99.9 % purity and 15 bar.

REDHy addresses the limitations of current electrolyser technologies by revolutionising water electrolysis, enabling it to overcome the drawbacks of AEL and PEMEL using bipolar membrane water electrolysis with redox couples as separate charge carriers for protons and hydroxide ions on opposite sides of the device, where hydrogen and oxygen are formed in two catalytic bed containers. A five-cell stack with ≥ 100 cm^2 active surface area per cell and ≥ 1.5 kW nominal power will be developed.

109 ANIONE – publishable summary.

110 ANIONE – periodic technical report.

High-temperature electrolysis projects

Solid oxide electrolyser projects

NewSOC aimed to produce high-performing and stable SOC electrodes, validated for large cells (> 50 cm^2 active area) and short stacks. It succeeded in improving the SoA of Ni/YSZ fuel electrodes aided by modelling.

MULTIPLHY will install and operate a 2.4 MW HT electrolyser system able to produce 60 kg H_2/h at a biofuel refinery in Rotterdam, covering about 1 % of the hydrogen demand of the facility[111].

REFLEX targeted reversible SOC technology and focused on improving rSOC components (cells, stacks, power electronics, heat exchangers). It produced second-generation enlarged cells (196 cm^2 vs 128 cm^2 SoA) and completed rSOC module design, assembly and field testing of two prototype modules (55 kW SOC and 10 kW SOFC) at SLS Actiparc with 5 632 hours of operation including 3 372 hours of operation above 650 °C, completing 135 cycles (16 hours SOFC and 8 hours SOEC).

PROMETEO has a novel approach to combining heat from concentrated solar systems with thermal energy storage to supply solar heat to an SOEL. A fully integrated and optimised system has been developed to increase electrical efficiency to above 85 % (LHV) while decoupling (on-demand) H_2 production from heat availability. A modular 25 kW SOEL prototype (15 kg H_2/d) will be designed, built, connected to representative external power/heat sources and validated through 1 000-hour tests.

REACTT is developing an MDPC for SOEL and rSOC stacks and systems. The project has developed a dynamic physically based model to reveal the relationships between SOC response and electrode reactions.

HyP3D aims to provide an SOEC stack with ultra-high-power density (2.14 kW delivered by 30 cells, which means 1.1 kW/kg) at a total scale of ≥ 10 kW which can operate for at least 2 000 hours. The electrodes will be produced with non-flat geometry via 3D printing, which allows pressurised operation of ≥ 5 bar.

OUTFOX aims to identify, develop and test SOEL cells and stack designs suitable for industrial-scale deployment. The 80 kW system will be validated with down-scaled industrial-scale cells (with a geometric area of 120 cm^2). The project will also develop a pilot manufacturing line with a production capacity of 2 000 industrial-scale cells.

PilotSOEL aims at contributing to lowering manufacturing costs of SOEC stacks through advanced, scalable manufacturing processes. Cells will be developed with improved efficiency and durability meeting the SRIA 2024 targets with respect to degradation rate and operating current density. The project has already reported on the use of testing protocols, including start-up and fingerprint protocols, as well as durability tests for single cells and stacks.

PressHyous will contribute to the development of pressurised SOEL systems. The project will develop a 20 kWe stack in a pressurised vessel able to deliver hydrogen at up to 30 bar, and a 10-bar pressurised stack (without a vessel).

NOAH2 will provide durable SOEL stack technology operable at ≤ 700 °C. A further contribution to achieving the SRIA targets is the capacity to operate at 1.2 A/cm^2 while keeping the degradation rate at ≤ 0.75 %/1 000 hours at stack level. Reduced CAPEX costs of EUR 520/(kg/d) and OPEX costs of EUR 45/(kg/d)/year are envisioned, meeting or even surpassing the SRIA 2030 targets.

Hy-SPIRE has similar aspirations to the NOAH2 project. Ultra-high temperature sintering will be explored by demonstrating its scalability and thereby shortening the fabrication time of electrochemically active components by one order of magnitude.

111 MULTIPLHY D2.1 (public).

Proton conducting ceramic electrolyser project

PROTOSTACK will develop a new stack design based on pressurised proton ceramic electrolysis technology. The stack will be integrated into a newly designed hot box for 5 kW operation up to 30 bar, and further evaluated in three use cases: a steel mill, a large-scale ammonia production plant and a chemical and energy plant owned by Shell. The project aims to advance the PCCEL technology from TRL 2 to TRL 4.

Other routes of renewable H_2 production projects

HYDROSOL-BEYOND aimed to demonstrate solar thermochemical hydrogen production at a 750 kW_{th} platform in Almeria, Spain. This proved to be more challenging than anticipated. The technology harnesses redox metal oxide thermochemical cycles to generate hydrogen. The high temperatures involved and the complexity of the process have led to numerous problems at the level of the materials, the reactors and the integration of the plant. Maintenance and temperature control have also been flagged up by the project as major difficulties.

HySelect will demonstrate the production of hydrogen by splitting water through the hybrid sulphur cycle, which involves high-temperature decomposition of sulphuric acid followed by sulphur dioxide depolarised electrolysis. The high-temperature stage of the cycle (900 °C) is reached via concentrated solar technology, while the electrolytic reaction is powered with solar-based electricity (concentrated solar technology or PV).

HYIELD investigates a new low-cost pathway for clean hydrogen production and waste disposal by proposing a novel multi-stage steam gasification and syngas purification plant concept utilising advanced waste-to-energy solutions, clean technology and an H2Site membrane separation reactor. It aims to efficiently convert different organic waste streams into hydrogen of 99.97 % expected purity at an energy conversion efficiency rate of > 65 %. It plans to build Europe's first large-scale 3 MW demonstrator at the CEMEX cement plant in Spain to run for 4 000 hours over a 15-month testing period with 10 different organic waste streams generating 650 tonnes of hydrogen to be used in the cement kiln.

PH2OTOGEN plans to build a scalable photocatalytic flow reactor for clean hydrogen production, in addition to creating value-added oxidation products through oxidation of organic molecules such as glycerol to produce 1,3-dihydroxyacetone oil, raising overall system revenues while generating solar hydrogen through a photocatalytic reaction.

PROJECT FACTSHEETS PILLAR 1

Low-temperature electrolysis projects

Alkaline electrolysis projects

DEMO4GRID
DJEWELS
EPHYRA
HYPRAEL
PEACE
ENDURE
EXSOTHYC
SEAL-HYDROGEN
X-SEED
OYSTER

Proton exchange membrane electrolysis projects

REFHYNE
HAEOLUS
ADVANCEPEM
HOPE

Anion exchange membrane electrolysis projects

CHANNEL
ANIONE
NEWELY
HYSCALE
HERAQCLES
AEMELIA
REDHY

High-temperature electrolysis projects

Solid oxide electrolyser projects

NEWSOC
MULTIPLHY
REFLEX
REACTT
HYP3D
OUTFOX
PILOTSOEL
PRESSHYOUS
NOAH2

Proton conducting ceramic electrolyser project

PROTOSTACK

Other routes of renewable H_2 production projects

HYDROSOL-BEYOND
HYSELECT
HYIELD
PH2OTOGEN

EIC Green Hydrogen Porfolio Projects

GH2

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

Clean Hydrogen Partnership
Co-funded by the European Union

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	
	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	
	Energy consumption	kWh/kg	< 52.8	
	Degradation	%/year	0.72	

EPHYRA

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

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 %	
	O_2 production (base case)	t/year	19 322	
	Current density	A/cm²	> 0.6	
	Electricity consumption @ nominal capacity	kWh/kg	≤ 49	
	Operating hours per year (base case)	h/year	3 945	
	O_2 production (full load)	t/year	39 184	
	Cold start ramp time	seconds	≤ 900	
	CO_2 savings for project duration (base case)	kt/year	52.6	
	O&M cost	€/(kg/day)/year	≤ 43 ± 10 %	
	Availability (full load)	%	91	
	Degradation	%/1 000 h	≤ 0.11	
	H_2 production (full load)	t/year	4 898	
	H_2 production (base case)	t/year	2 415	
	CO_2 savings for project duration (full load)	kt/year	108.1	
	LCOH targeted (full load)	€/kg H_2	2.6	
	LCOH targeted (base case)	€/kg H_2	3.3	
	Use of critical raw materials as catalysts	mg/W	< 0.6	
	Availability (base case)	%	45	
	Hot idle ramp time	seconds	≤ 30	
	Operating hours per year (full load)	h/year	8 000	

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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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

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	

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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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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. HI ERN 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	

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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.

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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

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	m^2/MW	50	
	Maintenance cost	€/(kg year)	20	
	Efficiency degradation at rated power	%/1 000 h	0.11	
	Current density	A/cm^2	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)	

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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/

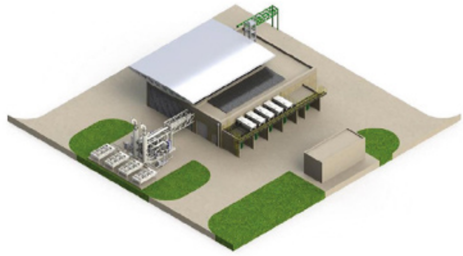
PROJECT AND GENERAL OBJECTIVES

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

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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

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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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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	

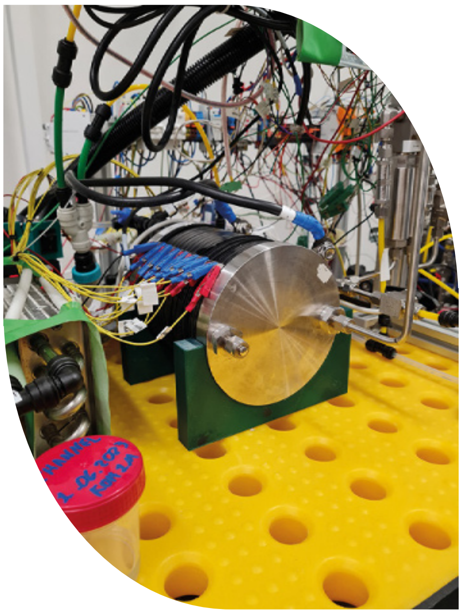
CHANNEL

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

CHANNEL

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.

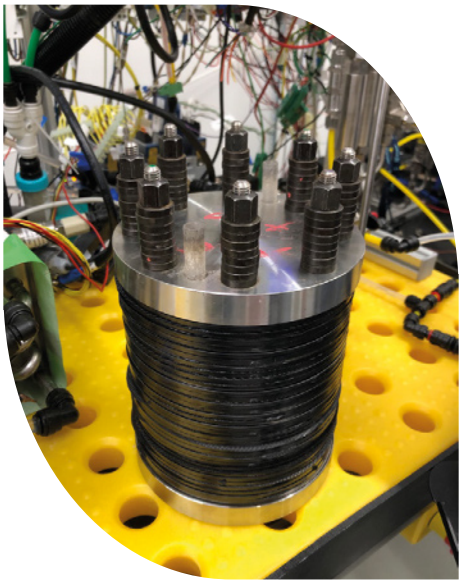
NON-QUANTITATIVE OBJECTIVES

- 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.

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

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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.

Clean Hydrogen Partnership
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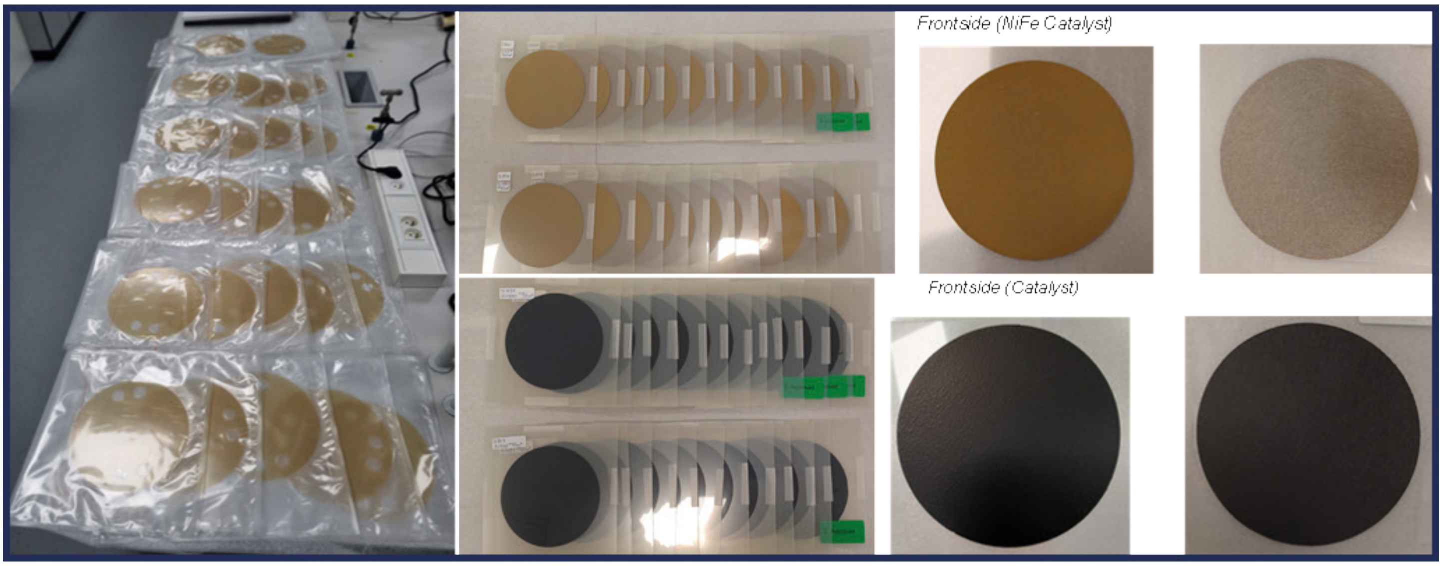
FUTURE STEPS AND PLANS

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



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/cm² 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/cm² 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 cm² 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		2.4	2021
	Cell area	cm²	200	25		N/A	2021
	Pressure	bar (relative)	≤ 40	N/A		≤ 35	2021
	Energy consumption @ power	kWh/kg @ W/cm²	53.6 @ 2	53.6 @ 3.6		53.6 @ 2.4	2021
	Corresponding to cell voltage @ current	Corresponding to V @ A/cm²	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/cm²	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		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		N/A	2021
	Chemically, thermally and mechanically stable AEM ionomer and membrane with conductivity	mS/cm	≥ 50	62	✓	80	2021
	Area-specific resistance	ohm/cm²	≤ 0.07	0.065	✓	0.045	2021

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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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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.

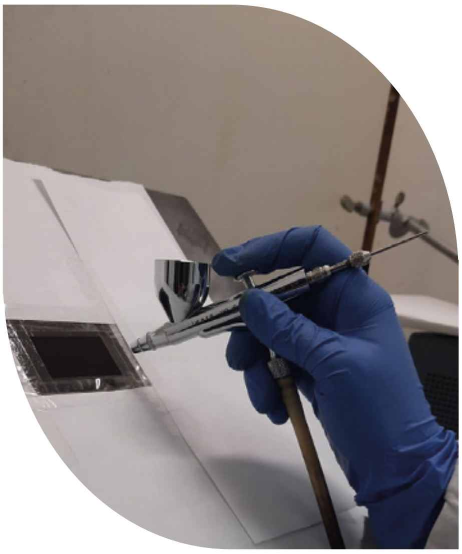
- Heraqcles will develop automated manufacturing processes for anion-exchange membrane (AEM) water electrolysers and validate a proof-of-concept 25 kW system operating at 30–50 bar with a hydrogen production rate of about 12.5 kg H_2/day (manufacturing readiness level 5) with detailed design and cost 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/cm²	
	Current density	A/cm²	1	
	O&M cost	€/(kg/day)/year	20	
	Voltage	V	1.8 V/cell at 1 A/cm² current density	
	Hydrogen cost	€/kg	2–3	
	Capital cost	€/(kg/day)	600	
	Use of CRMs as catalysts	mg/W	0	

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/cm^2) 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/cm^2 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/cm^2) 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/cm^2.

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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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 cm² 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/cm² 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 cm² 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/cm²) 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/cm² 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

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

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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

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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

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 non-linear 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

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	

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.

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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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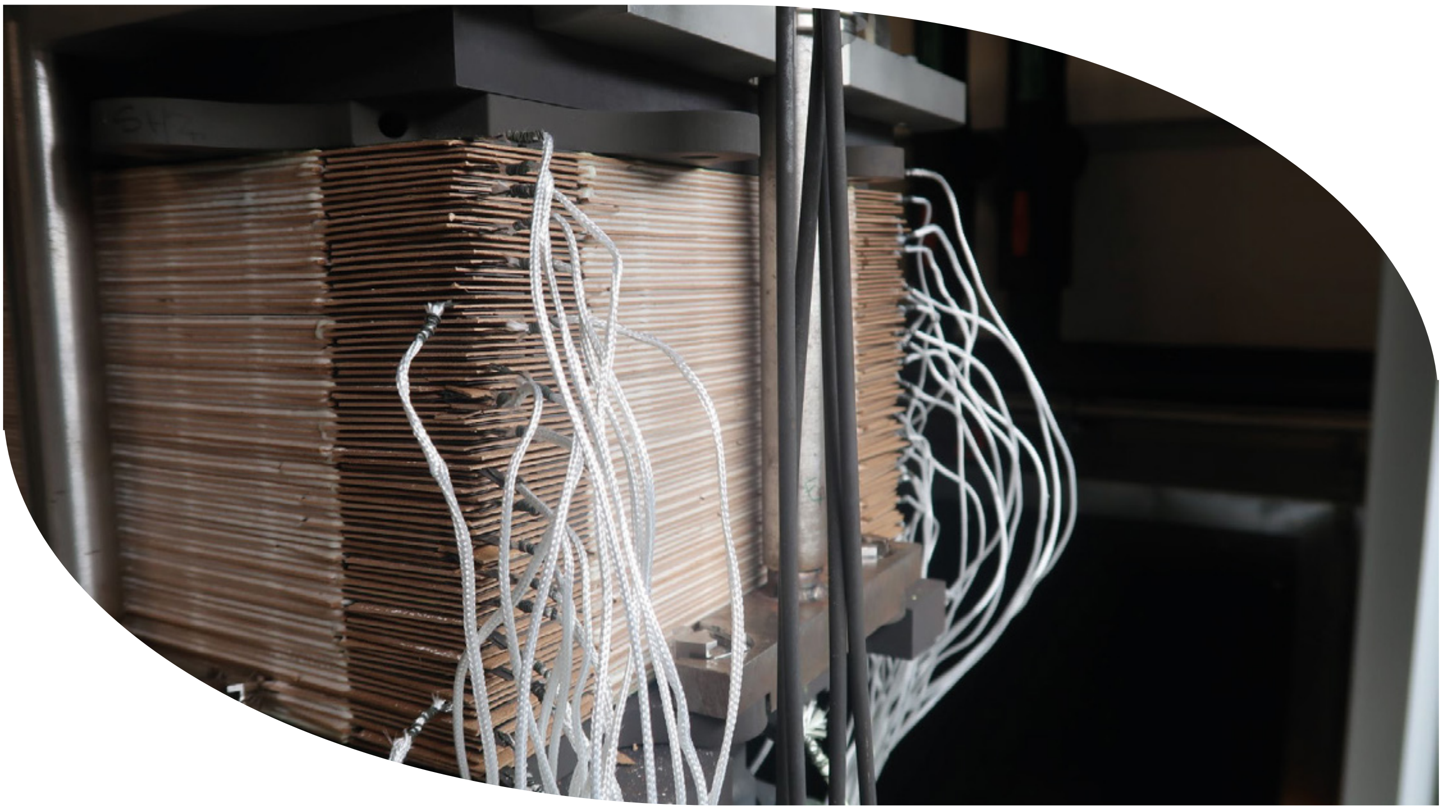
PROJECT TARGETS

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/cm^2	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



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

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

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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

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.

Clean Hydrogen Partnership
Co-funded by the European Union

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Development of structured SO_3-splitting catalysts with high activity and long-term stability	%	Loss of activity 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/m² receiver area	Average hydrogen production rates higher than 2.16 kg/day/m² 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	

HYIELD

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

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

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	

GH2

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

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

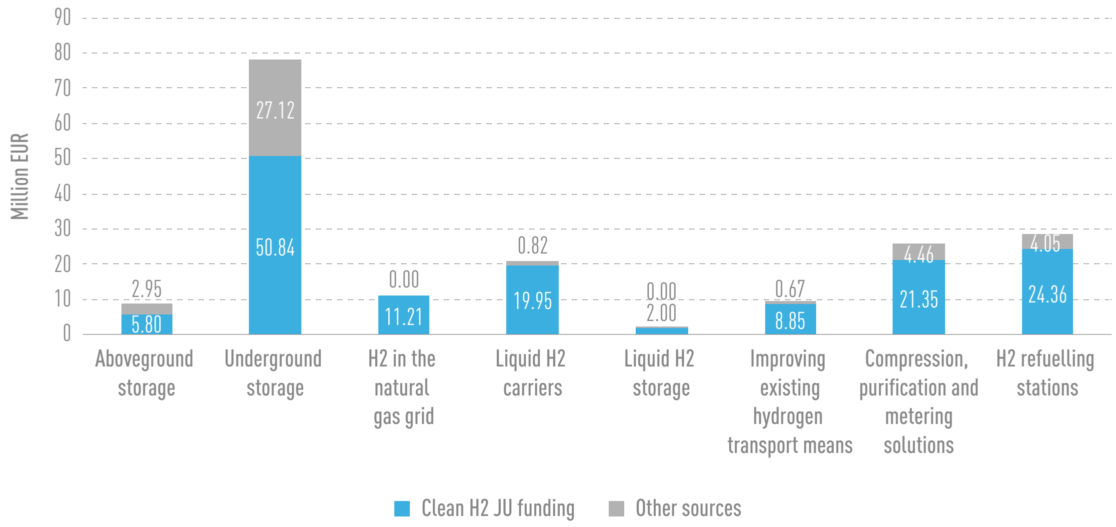
II. PILLAR 2 - HYDROGEN STORAGE AND DISTRIBUTION

OBJECTIVES: The pillar is subdivided into the following research areas:

- aboveground storage
- underground storage
- hydrogen in the natural gas grid
- liquid hydrogen carriers
- ∑iquid hydrogen storage
- improving existing hydrogen transport means
- hydrogen transport
- compression, purification and metering solutions
- hydrogen refuelling stations.

OPERATIONAL BUDGET: More than half of the projects grouped in this pillar were part of the 2023 programme review, which demonstrates the increased importance of topics relevant for pillar 2 in recent project calls (Figure 26).

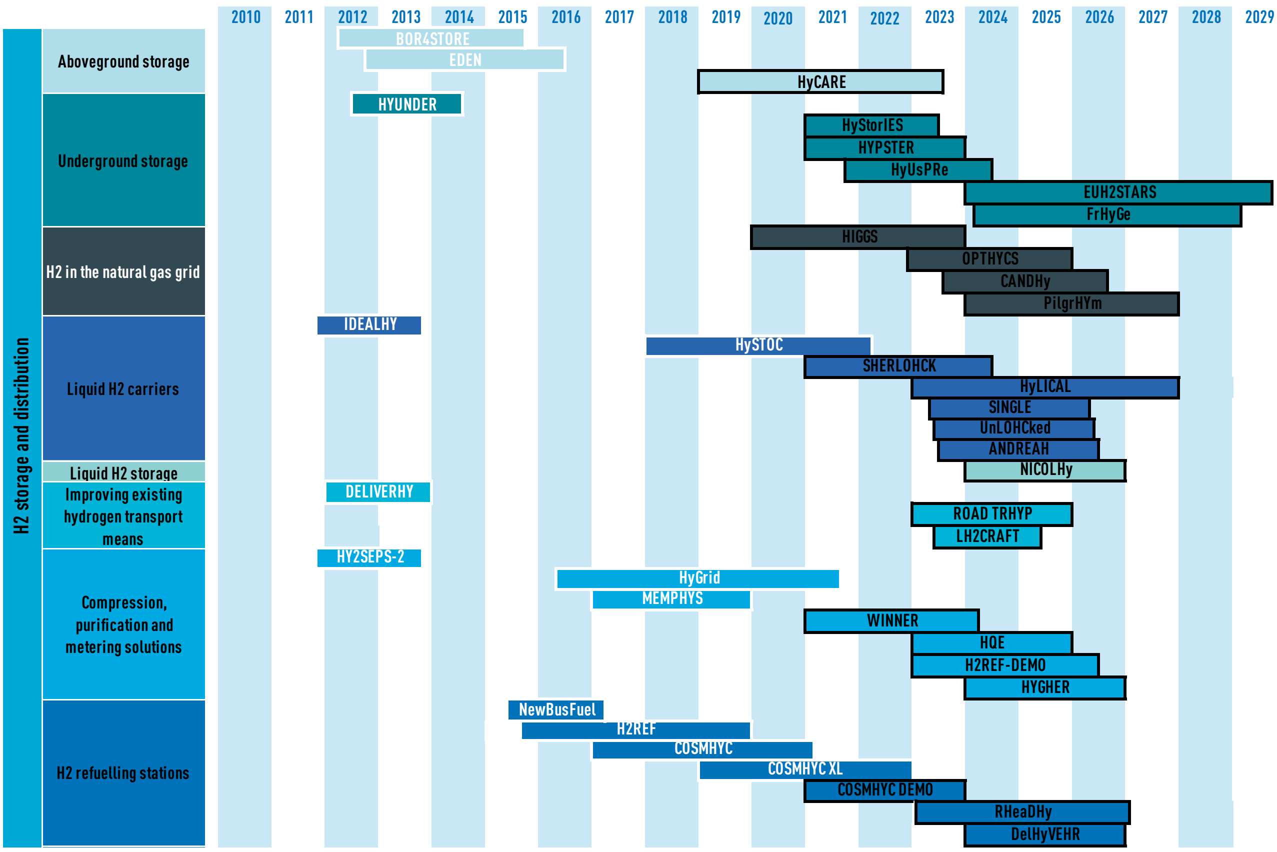
Figure 28: Funding for pillar 2 projects from 2008 to date



Source: Clean Hydrogen JU.

PROJECTS IN BRIEF: It is thought that the scale-up of hydrogen technologies and an increased focus on hydrogen trade, as expressed for instance by the hydrogen strategy and the REPowerEU plan, have spurred recent efforts in this field. Of the 38 projects listed in Figure 27, 26 started in 2019 or after. In particular, underground storage and solutions for hydrogen transport and storage in the form of liquid hydrogen or chemical carriers started to receive renewed attention from 2020.

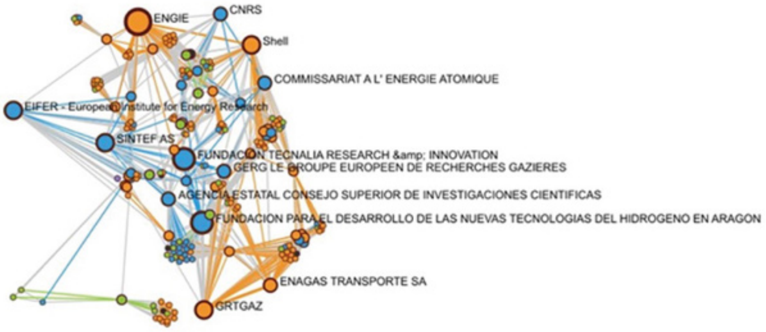
Figure 29: Project timelines for pillar 2 – hydrogen storage and distribution



Source: Clean Hydrogen JU.

Figure 29 reveals that a large number of research centres are involved in the projects of pillar 2. The size of the node represents the number of projects a partner is involved in, whilst the thickness of the links represents the number of projects in common between the linked partners. The colour is based on the type of organisation as provided in CORDIS. Among the private companies, Shell and ENGIE are the most prominent. There is a strong participation of TSOs and companies linked with energy commodities. There seem to be strong links between participants, with the exception of the HYPSTER project, which has no connections to any other project.

Figure 30: TIM plot showing the participants in the nine projects in pillar 2



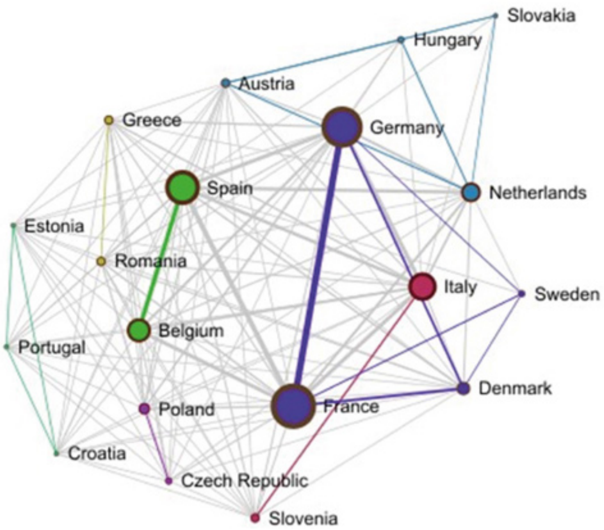
Top Participants

Participant	Number of Projects
ENGIE	6
FUNDACION TECNALIA RESEARCH & INNOVATION	5
FUNDACION PARA EL DESARROLLO DE LAS NUEVAS TECNOLOGIAS DEL HIDROGENO EN ARAGON	5
SINTEF AS	4
SHELL	4
GRTGAZ	4
EIFER	4

Source: TIM, JRC, 2024.

Among the Member States, France and Germany are in the lead of participation for this Pillar, which can be seen in Figure 31. This corresponds to the general trend seen for the whole Programme. The size of the node represents the number of projects that has at least one participating organisation from that country. The thickness of the links between the nodes is proportional to the number of projects those countries have in common. Of non-EU countries the most significant participations are Norway, and Switzerland and UK.

Figure 31: TIM plot showing EU Member State participation in pillar 2 projects



Member State	Number of Projects
France	20
Germany	18
Spain	15
Italy	12
Belgium	10

Source: TIM, JRC, 2024.

Aboveground storage projects

HYCARE has tested a large-scale hydrogen storage system based on solid-state storage solutions coupled with phase-change materials fitted inside a 20-foot container. The HYCARE system was tested at the ENGIE Lab CRIGEN laboratory in Île-de-France, integrating it with a PEM electrolyser and FCs. It consists of 4 tonnes of hydrogen storage material, divided into 12 tanks. The fully developed system has an estimated capacity of around 46 kg H_2 (less than 4 kg H_2 per tank), and 35 kg H_2 has been accessed using the 1-25 bar pressure range.

Underground storage projects

HYPSTER uses a salt cavern located in Etrez, in the Auvergne-Rhône-Alpes region, in France. A 1 MW PEM electrolyser will produce 400 kg of hydrogen per day. Testing operations have now started, which will be followed by 100 cycles of hydrogen pressure variation over 3 months. The cyclic testing is aimed at validating the modelling of various effects in the cavern, primarily focusing on thermodynamics but also potentially providing insights into geomechanical behaviour.

HYSTORIES aimed to assess the suitability of depleted fields, existing gas storage reservoirs and aquifers for hydrogen storage. One of the outcomes of HYSTORIES is a database, which was compiled from publicly available data and other sources such as well stratigraphy and logs. The database provides geological data on reservoir and seal characteristics for depleted hydrocarbon fields and saline aquifers. It is publicly accessible through a geographic information system, which highlights regions and sites that are potentially suitable for hydrogen storage from a geological standpoint[112]. A capacity estimation was carried out for the identified 800+ porous traps in EU-27 and four neighbouring countries, revealing around 6 850 TWh of onshore capacity (19 000 TWh for both onshore and offshore). Modelling has been carried out to assess the future storage needs. The project forecasts that after 2030, the required storage capacity in Europe could be over 300 TWh (compared to the current NG storage capacity of 1 000 TWh).

HYUSPRE aims to support decision makers in selecting appropriate sites for underground hydrogen storage. The project assessed existing NG storage sites for their suitability and drew up a list of criteria for the compilation of a ranking. According to the project, the vast majority of the identified sites (140 sites) have the potential to store hydrogen. This corresponds to a conversion potential of 320 to 415 TWh, depending on the NG storage capacity conversion rate applied.

H_2 in the natural gas grid projects

HIGGS studied the injection of high concentrations of hydrogen into the existing high-pressure gas grid, filling knowledge gaps about the impact on the gas infrastructure, its components and its management. It managed to demonstrate that all equipment (valves, joints and other grid elements) behaved in the same way under NG and hydrogen. In up to 3 000 hours of testing, the carbon steels tested did not show signs of embrittlement under hydrogen exposure. Also, a system able to separate low concentrations of hydrogen in NG was designed, built and successfully validated.

CANDHY aims to investigate the impact of hydrogen (as a mixture with NG and at up to 100 % purity) on low-pressure distribution grids. The testing will focus on non-steel metallic grid materials.

PilgrHYm aims to develop a pre-normative framework to support the creation of a European standard for transporting gaseous hydrogen through existing NG pipelines by conducting comprehensive testing on representative pipeline specimens to address safety concerns and research gaps.

OPTHYCS aims to develop and manufacture advanced sensor technologies using optical fibre sensors for safety applications. The project has three primary focus areas: analysing new sensor technologies; validating them in key use cases in controlled environments; and further assessing aspects of the technologies derived from the use cases, including the assessment of the security and environmental risks evaluations and regulatory framework, and performing a scalability and cost efficiency study.

112 https://hystories.eu/map/

Liquid H_2 carrier projects

SHERLOHCK aims to develop highly active and selective catalyst material, with partial, or if possible, total substitution of PGMs. It also has a target of reducing internal heat loss and increasing the (de)hydrogenation conversion rate. The project has achieved the hydrogen productivity in dehydrogenation target (3 g H_2/g catalyst/min), reaching a productivity level of 5.3 g H_2/g Pt/min.

UnLOHCked aims to develop and scale up a catalyst for the dehydrogenation of LOHCs without CRMs and to increase the efficiency of a dehydrogenation plant by developing an integrated system that is thermally coupled with an SOFC.

HYLICAL is the first project on liquefaction technology funded by the Clean Hydrogen JU since IDEALHY (2011-2013). A crucial objective of the project is the development of new magneto-caloric materials with reduced heavy rare earth content, addressing criticality aspects. The technology built on these novel materials is aimed at replacing conventional compressor-based liquefaction technologies, which, if successful, would enable a reduction in energy demand and improve scalability.

LH2CRAFT aims to revolutionise the storage and transportation of liquid hydrogen for commercial vessels by developing an innovative membrane-type containment system, creating a sustainable, efficient and safe solution for large-scale LH2 storage, reaching up to 200 000 m^3, and demonstrating it through a 10-tonne (180 m^3) prototype.

ANDREAH aims to improve the production of hydrogen from ammonia by developing cutting-edge ammonia decomposition technology. The novel system will use a CMR to enhance heat management, increase conversion rates and reduce the use of CRMs, thereby reducing costs compared to traditional methods.

SINGLE aims to demonstrate a proton ceramic electrochemical reactor that integrates ammonia dehydrogenation, hydrogen separation, heat management and compression in a single stage, with the goal of achieving energy conversion efficiencies of over 90 %.

Compression, purification and metering solution projects

WINNER develops PCCs for different applications: ammonia cracking for pressurised hydrogen, dehydrogenation of ethane and reversible electrolysis at high pressure. The project also aims at developing a purpose-built, 3D, multi-scale, multiphysics modelling platform, which will be used for the design of mechanically stable cells and modules. As a follow-up to the **GAMER** project, it has established synergies for the modelling activities; the development of materials and cells; and, at system integration level, especially for ammonia cracking and the scaling up of the demonstration system to 5 kW.

HQE seeks to study the quality of hydrogen fuel across Europe. To do so, 300 samples will be collected from at least 100 HRSs across the continent and analysed. The aim is to develop an open-source database of hydrogen quality in Europe, which is to be maintained for over 5 years after the end of the project, with its management eventually transferred to a neutral body. Ten analysis laboratories will be proficiency tested and three HRSs will be fitted with online analysers.

H2REF-DEMO aims for a peak dispensing capacity of 150 kg/h with a targeted cost of EUR 1 200/(kg/d). The process is expected to reduce electricity consumption to 3.5 kWh/kg of dispensed hydrogen from production on-site at 2 MPa to 42 MPa for a 35 MPa vehicle tank.

HYGHER aims to improve and scale up solutions for gaseous hydrogen delivery infrastructure for hydrogen mobility by developing innovative solutions, including a high-capacity filling centre that can compress over two tonnes of hydrogen per day, two high-pressure trailers and adaptations to HRSs for the full valorisation of high-pressure hydrogen delivery and utilisation.

H_2 refuelling station projects

COSMHYC XL[113] sought to advance compression technology by combining mechanical compression with metal hydride compression in a three-stage compressor.

COSMHYC DEMO is the continuation of COSMHYC XL. From 2023 onwards, the results of COSMHYC XL have continued to be disseminated through COSMHYC DEMO. The start-up company responsible for the metal hydride compressor which was created under COSMHYC XL is already part of COSMHYC DEMO. The project includes design, construction and integration of the metal hydride compressor demonstrator in a new HRS with a capacity of 200 kg H_2/d.

RHeaDHy aims to develop a high-performance HRS, including all necessary components, while implementing and validating the refuelling protocols developed in PRHYDE. The project aims to bring the developed components, including their standardisation and certification, to the market.

DelHyVEHR aims to develop and demonstrate a high-flow-rate-transfer cryogenic pump and boil-off gas management system for liquid hydrogen refuelling stations, enabling fast and efficient refuelling of HDVs in the shipping, aviation and rail sectors.

ROAD TRHYP aims to develop and demonstrate the suitability of trailers integrating type V thermoplastic composite tubes, incorporating regulation and end-user requirements on safety and decontamination capacity while maximising the amount of hydrogen transported with a low TCO. The project will include the design of a tube trailer with a payload of 1.5 tonnes of hydrogen with 700 bar tubes and a CAPEX of under EUR 400/kg of hydrogen.

113 COSMHYC XL does not have a poster because the consortium didn't participate in the 2024 data collection, so there is not sufficient information.

PROJECT FACTSHEETS PILLAR 2

Aboveground storage projects

HYCARE

Underground storage projects

HYPSTER
HYSTORIES
HYUSPRE

H_2 in the natural gas grid projects

HIGGS
CANDHY
PILGRHYM
OPTHYCS

Liquid H_2 carrier projects

SHERLOHCK
UNLOHCKED
HYLICAL
LH2CRAFT
ANDREAH
SINGLE

Compression, purification and metering solution projects

WINNER
HQE
H2REF-DEMO
HYGHER

H_2 refuelling station projects

COSMHYC DEMO
RHEADHY
DELHYVEHR
ROAD TRHYP

HYCARE

AN INNOVATIVE APPROACH FOR RENEWABLE ENERGY STORAGE BY A COMBINATION OF HYDROGEN CARRIERS AND HEAT STORAGE

Project ID	826352
PRR 2024	Pillar 2 – H_2 storage and distribution
Call topic	FCH-02-5-2018: Hydrogen carriers for stationary storage of excess renewable energy
Project total cost	EUR 2 024 230.00
Clean H_2 JU max. contribution	EUR 1 999 230.00
Project period	1.1.2019–31.7.2023
Coordinator	Università degli Studi di Torino, Italy
Beneficiaries	Centre national de la recherche scientifique, ENGIE, Fondazione Bruno Kessler, GKN Powder Metallurgy Engineering GmbH, Helmholtz-Zentrum Hereon GmbH, Institutt for energiteknikk, Parco Scientifico Tecnologico per l'Ambiente Environment Park Torino SpA, Stuehff GmbH (now SMasch), Tecnodelta SRL, Stühff Maschinen- und Anlagenbau GmbH

http://www.hycare-project.eu/

PROJECT AND GENERAL OBJECTIVES

The main objective of the Hycare project was to develop a prototype hydrogen storage tank using a solid-state hydrogen carrier on a large scale. The tank was based on an innovative concept combining hydrogen and heat storage to improve the energy efficiency of the whole system. The tank developed was joined with a proton exchange membrane electrolyser, as the hydrogen provider, and a proton exchange membrane fuel cell, as the hydrogen user, at the ENGIE Lab Crigen, located in Île-de-France. Hycare's integrated system was commissioned in spring 2023, and system testing and validation was performed up to October 2023.

NON-QUANTITATIVE OBJECTIVES

- **Safety.** The project aims to achieve low temperatures and pressures for storing hydrogen using carriers.
- **Energy efficiency.** The project aims to improve the energy efficiency of hydrogen storage using heat storage through phase change materials.

PROGRESS AND MAIN ACHIEVEMENTS

Those involved in the Hycare project were able to create a pilot plant with the capacity to store up to 46 kg of hydrogen at less than 50 bar and less than 100 °C in a 20 ft container. The pilot plant demonstrates that efficient energy storage by a solid-state hydrogen carrier is possible at a large scale and provides insights for further research and development and technology implementation at the societal level.

FUTURE STEPS AND PLANS

The project has finished.

The hydrogen storage tank will be available at SMasch's premises in Germany. SMasch will give potential customers and partners the opportunity to visit the Hycare hydrogen storage tank and its system, adding value to the project's results and the future development of the apparatus.

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
	Hydrogen storage capacity of the system	kgH_2	–	35.0 measured; 46.3 estimated		260	2021
	Cyclability	number of full cycles until a 2 % reduction in the gravimetric capacity of the H_2 carrier is reached	250	250		N/A	N/A
Project's own objectives	Volumetric capacity of H_2 carrier	kgH_2 per unit of volume of carrier	–	Reversible capacity at 55 °C between 1 and 25 bar of less than 70 (69.3)	✓	N/A	2021
	Gravimetric capacity of H_2 carrier	wt% of H_2 in the carrier	–	Reversible capacity at 55 °C between 2 and 20 bar of 1.1		N/A	
	Maximum pressure of the H_2 carrier tank	bar	< 50	40		N/A	2021

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HYPSTER

HYDROGEN PILOT STORAGE FOR LARGE ECOSYSTEM REPLICATION

Project ID	101006751
PRR 2024	Pillar 2 – H_2 storage and distribution
Call topic	FCH-02-7-2020: Cyclic testing of renewable hydrogen storage in a small salt cavern
Project total cost	EUR 15 514 301.73
Clean H_2 JU max. contribution	EUR 4 999 999.00
Project period	1.1.2021–31.12.2024
Coordinator	Storengy SAS, France
Beneficiaries	Association pour la Recherche et le Développement des Méthodes et Processus Industriels, Axelera – Association Chimie-Environnement Lyon et Rhone-Alpes, École polytechnique, Element Energy Limited, Environmental Resources Management Limited, Equinor Energy AS, ERM France, ESK GmbH, Inovyn Chlorvinyls Limited, Institut national de l'environnement industriel et des risques SAS, Brouard Consulting, Storengy France

https://hypster-project.eu/

PROJECT AND GENERAL OBJECTIVES

Hypster aims to demonstrate the industrial-scale operation of cyclical hydrogen storage in salt caverns to support the emergence of the hydrogen energy economy in Europe in line with Hydrogen Europe's overall roadmap. The cavern is located in Etrez in Auvergne-Rhône-Alpes, France. For the production of green hydrogen, the Etrez storage site will rely on local renewable energy sources and a 1 MW proton exchange membrane electrolyser. In the long run, this facility will produce 400 kg of hydrogen per day (equivalent to the hydrogen consumption of 16 hydrogen-powered buses). The objective of the project is to test industrial-scale green hydrogen production and storage in salt caverns and the technical and economic reproducibility of the process in other sites throughout Europe.

NON-QUANTITATIVE OBJECTIVES

- Assessment of the economic feasibility of the process.
- Measurement of risk and environmental impacts.
- Definition of guidelines for regulation and normative adaptation in Europe.
- Study of its techno-economic replicability in Europe.
- Microbiological analysis.

PROGRESS AND MAIN ACHIEVEMENTS

- The workover of the EZ53 well was successfully completed in 2023.
- All works (civil, piping, electrical, instrumentation, automation) have been carried out and all equipment procured has been installed and connected, except the electrolyser stacks.
- Numerical simulation models for hydrogen storage in the salt cavern have been adapted.
- A risk analysis of underground hydrogen storage in the salt cavern has been performed.
- Commercial and microbiological analyses have started.
- The cold commissioning of the electrolyser has started (without hydrogen).
- The opening of the site was held in September 2023.

FUTURE STEPS AND PLANS

- Delivery of stacks in April 2024.
- Conduct of hydrogen tightness tests in April–May 2024.
- Conduct of hydrogen cycling tests, starting in June 2024.
- Production of hydrogen, starting in June–July 2024.
- Delivery of final workshop and wrapping up of the project in August–December 2024.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
MAWP addendum (2018–2020)	OPEX	€/kg	1	
	Power	MW	1	
	H_2 mass	kg	2 000	
	CAPEX	€/kg	450	

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HYSTORIES

HYDROGEN STORAGE IN EUROPEAN SUBSURFACE

Project ID	101007176
PRR 2024	Pillar 2 – H_2 storage and distribution
Call topic	FCH-02-5-2020: Underground storage of renewable hydrogen in depleted gas fields and other geological stores
Project total cost	EUR 2 499 911.75
Clean H_2 JU max. contribution	EUR 2 499 911.75
Project period	1.1.2021–30.6.2023
Coordinator	Geostock SAS, France
Beneficiaries	Consejo Superior de Investigaciones Científicas, Bureau de Recherches Geologiques et Minieres, Česká geologická služba, Réseau d'excellence européen sur le stockage géologique de CO_2, Ethniko Kentro Erevnas Kai Technologikis Anaptyxis, Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón, Geoinženiring družba za geološki inženiring d.o.o., Geological Survey of Denmark and Greenland, Geologische Bundesanstalt, Geosphere Austria – Bundesanstalt für Geologie, Geophysik, Klimatologie und Meteorologie, Główny Instytut Górnictwa, Helmholtz-Zentrum Potsdam Deutsches GeoForschungsZentrum GFZ, Institut royal des Sciences naturelles de Belgique, Instituto Geológico y Minero de España, Institutul Național de Cercetare – Dezvoltare pentru Geologie și Geoecologie Marină –GeoEcoMar, Instytut Gospodarki Surowcami Mineralnymi i Energia PAN, Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Ludwig-Bölkow-Systemtechnik GmbH, Micropro GmbH, Middle East Technical University, Montanuniversität Leoben, NORCE Norwegian Research Centre AS, Sveučilište u Zagrebu Rudarsko-geološko-naftni fakultet, Tallinna Tehnikaülikool, UK Research and Innovation, Universidade De Évora

https://hystories.eu/

PROJECT AND GENERAL OBJECTIVES

The Hystories project, explored underground hydrogen storage in Europe from 1 January 2021 to 30 June 2023. Led by Geostock, it involved key partners across Europe and gathered geological data from 23 countries. The project focused on salt caverns and porous media (depleted liquid or gaseous hydrocarbon reservoirs, saline aquifers).

The current industrial experience of pure hydrogen storage is limited, with only a few projects in Europe and the United States. While the storage of town gas (a mixture containing hydrogen) in porous media has a historical precedent, the storage of pure hydrogen presents new challenges, particularly due to Hydrogen's reactivity, its ability to embrittle steels and its low viscosity and volumetric energy density.

The main objectives of the Hystories project were to bring technical developments to large-scale renewable hydrogen storage in depleted fields or aquifers and to assess how underground hydrogen storage could facilitate the transition to a CO_2-emission-neutral energy system in the EU by 2050.

PROGRESS AND MAIN ACHIEVEMENTS

The project identified potential underground hydrogen storage sites in porous media and estimated their total hydrogen storage capacity at 6 850 TWh (19 000 TWh including offshore sites) in the EU and neighbouring countries.

A risk analysis method associated with microbial activity in future underground hydrogen storage was proposed, and hydrogen consumption was modelled. The results showed hydrogen consumption of 0.06 % at the laboratory scale and 0.004 % at the storage scale after five seasonal hydrogen injection and withdrawal cycles. A dozen common steel grades for oil tubing were tested in the presence of hydrogen, and recommendations were issued on the type of steel to be used in storage.

In conclusion, underground hydrogen storage has significant potential to contribute to the decarbonisation of energy networks and societies, especially in Europe. Storage in salt caverns is considered technically mature. No major technical impediments of storage in depleted fields or aquifers were identified, although questions remain regarding the quality of the gas released and the potential costs of treatment required to enable its reinjection into hydrogen distribution networks. The project also highlighted the importance of the regulatory framework and business models for the deployment of storage sites, and the need for further investigation into cost estimation and the role of underground hydrogen storage in the energy value chain.

FUTURE STEPS AND PLANS

The project has finished.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
MAWP addendum (2018–2020)	Large-scale H_2 storage / capital cost	€/kg	0.6	0.017 (salt); 0.011 (porous)	✓
	Energy used in large-scale H_2 storage / release	MWh/kg	9.3	1.7 (salt); 2.5 (porous)	
	Large-scale H_2 storage / chain efficiency	%	72	95 (salt); 92.5 (porous)	

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HYUSPRE

HYDROGEN UNDERGROUND STORAGE IN POROUS RESERVOIRS

Project ID	101006632
PRR 2024	Pillar 2 – H_2 storage and distribution
Call topic	FCH-02-5-2020: Underground storage of renewable hydrogen in depleted gas fields and other geological stores
Project total cost	EUR 3 714 850.00
Clean H_2 JU max. contribution	EUR 2 499 850.00
Project period	1.10.2021–30.6.2024
Coordinator	Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek, Netherlands
Beneficiaries	Centrica Storage Limited, Energie Beheer Nederland BV, Energieinstitut an der Johannes Kepler Universität Linz Verein, Equinor Energy AS, Fondazione Bruno Kessler, Forschungszentrum Jülich GmbH, Magyar Földgáztároló Zrt., NAFTA AS, Neptune Energy Hydrogen BV, RAG Austria AG, Shell Global Solutions International BV, SNAM SpA, Technische Universität Clausthal, University of Edinburgh, Uniper Energy Storage GmbH, Wageningen University

https://www.hyuspre.eu/

PROJECT AND GENERAL OBJECTIVES

Hyuspre studied the potential of large-scale hydrogen storage in porous reservoirs in Europe. This includes the identification of suitable geological storage reservoirs and a techno-economic feasibility assessment for hydrogen storage in these reservoirs. Hyuspre addressed specific technical challenges regarding storage, and involved the conduct of an economic analysis to facilitate the decision-making process to develop a portfolio of potential field pilots. The techno-economic assessment enabled the development of a roadmap for widespread hydrogen storage towards 2050.

NON-QUANTITATIVE OBJECTIVES

- Hyuspre aimed to conduct a study assessing potential matches between hydrogen supply and demand sites, including the need for hydrogen to buffer time-varying renewable energy demands.
- The project aimed to conduct a study on the potential of European underground hydrogen storage to facilitate the achievement of a zero-emission energy system by 2050.

PROGRESS AND MAIN ACHIEVEMENTS

After the extension of Hyuspre by 6 months until June 2024, the project operated according to plan. Laboratory experiments were concluded in March 2024, and results were subsequently analysed and reported. The hydrogen scenario studies (on the EU-scale H_2 system, guidelines for decision-making on reservoir suitability, levelised cost of hydrogen and hydrogen roadmap for Europe) were developed in close cooperation with the project's industrial partners.

FUTURE STEPS AND PLANS

Hyuspre is in its concluding phase. The consortium concluded all planned activities and delivered all planned deliverables by the end of June. A fifth webinar was offered on the European hydrogen roadmap in June. The final conference was held on 19 June in the Netherlands.

PROJECT TARGETS

Target source	Parameter	Target achieved?
Project's own objectives	Develop future scenario roadmaps for EU-wide implementation	
	Evaluate the amount of renewable energy that can be buffered versus time-varying demands	⚙
	Establish a cost estimate and identify the business case for H_2 storage in porous reservoirs	
	Visualise suitable H_2 underground stores and their H_2 storage potential based on GIS	
	Establish geochemical, microbial, flow and transport, and geomechanical processes for H_2 in porous reservoirs	✓
	Map the proximity of hydrogen stores to large renewable energy infrastructures	

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HIGGS

HYDROGEN IN GAS GRIDS: A SYSTEMATIC VALIDATION APPROACH AT VARIOUS ADMIXTURE LEVELS INTO HIGH-PRESSURE GRIDS

Project ID	875091
PRR 2024	Pillar 2 – H_2 storage and distribution
Call topic	FCH-02-5-2019: Systematic validation of the ability to inject hydrogen at various admixture level into high-pressure gas networks in operational conditions
Project total cost	EUR 2 107 672.50
Clean H_2 JU max. contribution	EUR 2 107 672.50
Project period	1.1.2020–31.12.2023
Coordinator	Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón, Spain
Beneficiaries	Deutscher Verein des Gas- und Wasserfaches – Technisch-Wissenschaftlicher Verein EV, European Research Institute for Gas and Energy Innovation, Fundacion Tecnalia Research and Innovation, OST – Ostschweizer Fachhochschule, Redexis SA

www.higgsproject.eu/

PROJECT AND GENERAL OBJECTIVES

HIGGS aimed to fill in the gaps in knowledge of the impact that high levels of hydrogen could have on high-pressure natural gas infrastructure, its components and its management. To reach this goal, the project has developed a mapping of technical, legal and regulatory barriers and enablers; tested materials/components; completed techno-economic modelling; and finally concluded preparing a set of conclusions as a pathway towards enabling the injection of hydrogen into high-pressure gas grids.

NON-QUANTITATIVE OBJECTIVES

- Compile recommendations for regulations, codes and standards according to current and future regulation/standardisation.
- Forge a pathway for the stepwise integration of hydrogen into the EU gas network, to improve the potential of hydrogen injection by 2030 and 2050.
- Create a techno-economic model and study of the roles of technologies for integrating H_2/CH_4 and sector coupling at the EU level.

PROGRESS AND MAIN ACHIEVEMENTS

- The testing platform has enabled dynamic and static tests to be carried out with blends of 20 mol % H_2, 30 mol % H_2 and 100 % H_2.
- The project has adopted the techno-economic model, and several scenarios have been modelled.
- A system has been created for separating low concentrations of hydrogen in natural gas. The experimental campaign with the gas separation prototype was successful.
- The gas tightness of valves of different natures and joints has been proved for hydrogen blends and 100 % hydrogen. The equipment of the gas grid behaved the same way as when natural gas was transported.
- The tested carbon steels showed no signs of embrittlement due to hydrogen exposure.
- A complete set of findings has been provided to predict what will be expected from gas grids until 2050.

FUTURE STEPS AND PLANS

The project has finished.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Blending percentage of H_2 compatible with existing gas transmission networks	%	100	✓
	Readiness of gas transmission networks for H_2 distribution	%	Complete inventory	
	Techno-economic approach to grid repurposing	%	Model scenarios	

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CANDHY

COMPATIBILITY ASSESSMENT OF NON-STEEL METALLIC DISTRIBUTION GAS GRID MATERIALS WITH HYDROGEN

Project ID	101111893
PRR 2024	Pillar 2 – H_2 storage and distribution
Call topic	HORIZON-JTI-CLEANH2-2022-02-01: Compatibility of distribution non-steel metallic gas grid materials with hydrogen
Project total cost	EUR 2 607 481.25
Clean H_2 JU max. contribution	EUR 2 607 481.00
Project period	1.9.2023–31.8.2026
Coordinator	Fundación para el Desarrollo de las Nuevas Tecnologias del Hidrógeno en Aragón, Spain
Beneficiaries	Fundacion Tecnalia Research and Innovation, Groupe Européen de Recherches Gazières, GRTgaz, Redexis Gas Servicios SL, Redexis SA, RINA Consulting – Centro Sviluppo Materiali SpA, Sumnistros Industriales Diversos SA, Università degli studi di Bergamo

http://candhy.eu/

PROJECT AND GENERAL OBJECTIVES

- Performing a full review of the state of art of the European gas distribution grids, the standards and codes for testing regarding material compatibility with hydrogen, and hydrogen embrittlement mechanisms to collect information for the development of useful testing protocols to derive the properties of the classes of materials studied in Candhy in their relevant operating conditions.
- Designing, developing and performing an experimental campaign to test the most relevant non-steel metallic materials found in Candhy under different hydrogen levels to assess their tolerance of this gas in the operating conditions usual for the distribution grid.
- Documenting and analysing the effect of hydrogen gas on the non-steel metallic materials tested in the experimental campaign mentioned previously.
- Developing models for the prediction of hydrogen embrittlement mechanisms.
- Proposing guidelines, procedures and areas of development to support the future standardisation of the testing and qualification of materials in the distribution network in the presence of H_2 / natural gas blends.
- Developing a technical database on the hydrogen compatibility of metals as a tool to aid in the selection of materials for use in hydrogen gas distribution.

PROGRESS AND MAIN ACHIEVEMENTS

- A questionnaire has been created and distributed among European distribution system operators and gas associations to collect data that will allow the determination of the current status of the grid, regarding the materials involved and other relevant parameters, and the operating conditions.
- The state-of-the-art development of relevant standards useful for studying embrittlement phenomena in non-steel metallic material is under progress. These standards will allow the definition of the conditions of the experimental campaign that will be developed next year.

FUTURE STEPS AND PLANS

- Completing an inventory of the gas grid.
- Extrapolating results of the review on current standards to define those relevant to the experimental campaign.
- Starting an experimental campaign on non-steel metallic materials with a round robin test.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Study of impact of hydrogen on non-steel metallic materials	number of materials analysed	Cover at least five types of material	
	Inventory of materials of the distribution grid	–	Collect as much information as possible from European DSOs	
	Review of state-of-the-art standards related to hydrogen embrittlement tests	number of standards	Review as many standards as possible	
	Database of compatible non-steel metallic materials	number	Create one database	
	Semi-empirical model to predict hydrogen embrittlement mechanisms	number	Construct one model to anticipate embrittlement	
	Harmonised guidelines	number	Propose harmonised guidelines for future standardisation	

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PILGRHYM

PRE-NORMATIVE RESEARCH ON INTEGRITY ASSESSMENT PROTOCOLS OF GAS PIPES REPURPOSED TO HYDROGEN AND MITIGATION GUIDELINES

Project ID	101137592
PRR 2024	Pillar 2 – H_2 storage and distribution
Call topic	HORIZON-JTI-CLEANH2-2023-02-02: Pre-normative research about the compatibility of transmission gas grid steels with hydrogen and development of mitigation techniques
Project total cost	EUR 3 999 073.75
Clean H_2 JU max. contribution	EUR 3 999 073.75
Project period	1.1.2024–31.12.2027
Coordinator	GRTgaz, France
Beneficiaries	Commissariat à l'Énergie Atomique et aux Énergies Alternatives, Enagás Transporte SA, Fluxys Belgium SA, Fraunhofer-Gesellschaft zur Förderung der Angewandten Forschung EV, Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón, Fundacion Tecnalia Research and Innovation, Groupe Européen de Recherches Gazières, Onderzoekscentrum voor Aanwending van Staal NV, Sintef AS, Snam SpA, Universidad de Burgos

http://pilgrhym.eu/

PROJECT AND GENERAL OBJECTIVES

The main goal of Pilgrhym is to provide a European roadmap for safely and efficiently integrating pure H_2 into existing natural gas infrastructure, contributing to the decarbonisation of the energy sector. To achieve this goal, Pilgrhym has set forth an ambitious objective of providing transmission system operators with comprehensive guidelines to assess the feasibility of using pure H_2 in existing natural gas pipelines.

To reach the previously stated goals, Pilgrhym has established seven technical and non-technical specific objectives (SOs), interconnected with the project's results, key performance indicators and work packages.

- Develop a database of material characterisation testing on representative steel grades of the EU gas grids, including tensile properties, fracture toughness and fatigue crack growth properties.
- Establish a harmonised testing protocol to support the repurposing of natural gas lines to accommodate hydrogen.
- Develop a numerical modelling approach for simulating and predicting hydrogen-assisted fracture and fatigue.
- Produce a more realistic fatigue crack growth rate master curve for the purpose of assessing fitness for service, in particular for low K values corresponding to the actual operating domain of the EU gas grids.
- Identify existing and/or innovative technologies for mitigation compatible with operational constraints.
- Engage with stakeholders to ensure cooperation and awareness.
- Facilitate the uptake and exploitation of Pilgrhym results by the academic community, technology developers and end users.

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OPTHYCS

OPTIC FIBRE-BASED HYDROGEN LEAK CONTROL SYSTEMS

Project ID	101101415
PRR 2024	Pillar 2 – H_2 storage and distribution
Call topic	HORIZON-JTI-CLEANH2-2022-02-02: Hydrogen and H2NG leak detection for continuous monitoring and safe operation of HRS and future hydrogen/H2NG networks
Project total cost	EUR 2 499 428.75
Clean H_2 JU max. contribution	EUR 2 499 428.75
Project period	1.1.2023–31.12.2025
Coordinator	Enagás Transporte SA, Spain
Beneficiaries	FEBUS Optics, Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón, Fundacion Tecnalia Research and Innovation, Groupe Européen de Recherches Gazières, GRTgaz, Lumiker Aplicaciones Tecnológicas SL

https://opthycs.eu/

PROJECT AND GENERAL OBJECTIVES

The Opthycs project aims to develop a new system for continuous leak detection based on optic fibre sensor technologies, ensuring the safety and sustainability of a hydrogen-based energy system.

Acknowledging the critical need for effective leak detection methods in light of the environmental impact of hydrogen emissions, Opthycs introduces an innovative approach by developing a solution that includes cutting-edge coating materials for fibre Bragg gratings (FBGs) and the creation of a combined detection system merging FBGs with distributed acoustic and temperature-based detection technologies.

PROGRESS AND MAIN ACHIEVEMENTS

In the first year, the project enabled the determination of the design specifications and requirements of the system from the technical, environmental and economical perspectives.

Progress has also been made in the development of sensor solutions. Coating materials for FBG sensors are developed using advanced plasma techniques, ensuring properties such as coating adhesion and increased hydrogen sensitivity.

The first tests for the development of the combined system (merging three different technologies), and the development of the interrogator and interpretative software have taken place in recent months.

FUTURE STEPS AND PLANS

Coating materials for FBG sensors will continue to be developed using advanced plasma techniques. A test bench will evaluate sensor responses under different environmental conditions during laboratory testing, controlling variables such as temperature, humidity and hydrogen concentration.

The development of FBG interrogators is another critical element of the project, involving advancements such as the integration of optical components for signal amplification and the testing of configurations allowing the measurement of a large number of sensors with a single interrogator. This breakthrough significantly increases the scalability of the system while maintaining accuracy and response time.

The final stage of Opthycs includes validating the combined H_2 detection system in predefined use cases, such as pipelines, hydrogen refuelling stations and gas grid installations.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Minimum leak concentration detected	%	0.4	
	Time of response	seconds	30, with a maximum response time of 1 s at a concentration of 0.4 % volume	
	Detection threshold	l_n/min	0.4 (blending operation); 1.2 (pure H_2)	
	Time of recovery	seconds	60/20 depending on application	

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SHERLOHCK

SUSTAINABLE AND COST-EFFICIENT CATALYST FOR HYDROGEN AND ENERGY STORAGE APPLICATIONS BASED ON LIQUID ORGANIC HYDROGEN CARRIERS: ECONOMIC VIABILITY FOR MARKET UPTAKE

Project ID	101007223
PRR 2024	Pillar 2 – H_2 storage and distribution
Call topic	FCH-02-1-2020: Catalyst development for improved economic viability of LOHC technology
Project total cost	EUR 2 563 322.50
Clean H_2 JU max. contribution	EUR 2 563 322.50
Project period	1.1.2021–30.6.2024
Coordinator	Commissariat à l'Énergie Atomique et aux Énergies Alternatives, France
Beneficiaries	Evonik Operations GmbH, Friedrich-Alexander-Universität Erlangen-Nürnberg, Hydrogenious LOHC Technologies GmbH, Kuwait Petroleum Research & Technology BV, Noordwes-Universiteit, Universidad del País Vasco / Euskal Herriko Unibertsitatea

https://sherlohck.eu/

PROJECT AND GENERAL OBJECTIVES

Liquid organic hydrogen carriers are attractive owing to their ability to safely store large amounts of hydrogen (up to 7 wt% or 2 300 kWh/t) for a long time and to release pure hydrogen on demand. The project targets the development of (i) highly active and selective catalysts with partial/total substitution of platinum group metals (PGMs); (ii) a novel catalytic system architecture, with components ranging from the catalyst to the heat exchanger, to minimise internal heat loss and to increase the space–time yield; and (iii) novel catalyst testing, system validation and demonstration through the demonstration unit (> 10 kW, > 200 h).

PROGRESS AND MAIN ACHIEVEMENTS

Requirements have been defined for the hydrogenation and dehydrogenation catalyst, the type and quality of liquid organic hydrogen carriers, hydrogen quality, the testing routine and energy consumption; these are compatible with all the objectives of the project. This initial work has laid the foundation for the whole project. Benzyltoluene was chosen as the reference molecule, and Pt-based catalysts from Clariant were selected as the catalysts' benchmark.

The design of a catalyst through density functional theory predictive analysis has reduced the use of PGM catalysts. Calculations were applied to the dehydrogenation of methylcyclohexane (to toluene) as a reference molecule, as benzyltoluene was too complex for the calculation. The overall dehydrogenation energies calculated for the various alloys considered showed that alloys such as Co, Co_3Pt, SnPt, Sn_3Pt_2, Sn_2Pt and Sn_4Pt could be potential low-Pt-based catalytic materials. Catalyst materials have been synthesised and tested on a laboratory scale with a standardised test protocol. Some Pt-X (X = Fe, Zn, Co or Cu) catalysts supported by alumina outperform the benchmark catalyst in terms of activity. Pt-Co, with a cobalt content of 0.5 wt%, achieved almost the same dehydrogenation activity and selectivity as catalysts with 1 wt% Pt but with half the amount of this noble metal. PGM-free catalysts have very low activity. Furthermore, through experiments with model substances simulating by-product formation, it was possible to gain better insights into the dehydrogenation reaction and catalyst deactivation. Promising results were initially obtained for the first catalyst reactivation by oxidative regeneration with synthetic air procedures executed in batch operations.

In parallel, to explore the advantages of structured heat-exchanger reactors combined with improved catalysts, models were constructed and simulations were performed to support the choice of possible reactor geometries, in particular to define suitable heat-conductive reactor structures. The results indicated that, for both reactions, foam structure, catalyst activity, mass and operating conditions are first-order parameters. 3D monolith structures were prepared to integrate catalyst materials, and a long-term testing campaign was launched, which ran up to June 2024.

FUTURE STEPS AND PLANS

- Sherlohck has integrated the catalyst into the thermally conductive support structure.
- Long-term testing in continuous operation (> 200 h) was ongoing until June 2024.
- Testing of the resistance of catalysts to different poisons is ongoing.
- The modelling of the reaction kinetics for the design of new reactors has started for the dehydrogenation reaction.

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	Catalyst selectivity	%	99.8	99.4		Around 100	2022
	Degree of conversion	%	90	88		Around 100	2022
	Catalyst productivity in dehydrogenation	gH2 / g catalyst / min	3	0.85	✓	0.85	2022

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UNLOHCKED

UNLOCKING THE POTENTIAL OF LOHCS THROUGH THE DEVELOPMENT OF KEY SUSTAINABLE AND EFFICIENT SYSTEMS FOR DEHYDROGENATION

Project ID	101111964
PRR 2024	Pillar 2 – H_2 storage and distribution
Call topic	HORIZON-JTI-CLEANH2-2022-02-05: Efficient system for dehydrogenation of liquid organic hydrogen carriers for application to long distance transportations
Project total cost	EUR 2 941 312.75
Clean H_2 JU max. contribution	EUR 2 941 312.75
Project period	1.6.2023–31.5.2026
Coordinator	Universidad del País Vasco / Euskal Herriko Unibertsitatea, Spain
Beneficiaries	Centre national de la recherche scientifique, Commissariat à l'Énergie Atomique et aux Énergies Alternatives, Framatome GmbH, Heraeus Deutschland GmbH & Co. KG, HyGear BV, HyGear Fuel Cell Systems BV, HyGear Hydrogen Plant BV, HyGear Operations BV, HyGear Technology And Services BV, Noordwes-Universiteit

https://unlohcked.cnrs.fr/

PROJECT AND GENERAL OBJECTIVES

By advancing breakthrough research on liquid organic hydrogen carrier (LOHC) technologies, Unlohcked aims to develop a radically disruptive, versatile and scalable LOHC dehydrogenation plant. Firstly, highly active and stable catalysts not containing critical raw materials (CRMs) will be developed to reduce LOHC dehydrogenation at moderate temperatures. Secondly, a solid oxide fuel cell system will be developed to be thermally integrated in the dehydrogenation process. The heat demand of the dehydrogenation unit will be fully covered by the fuel cell, while generating electric power. The surplus of hydrogen will be exported. These innovative systems, when fully integrated, will significantly increase the overall efficiency (> 50 %) of hydrogen and electric power production from LOHCs.

The main objectives of this project are:

- to develop a CRM-free or low-CRM catalyst with a high conversion rate, selectivity and productivity for dehydrogenation;
- to scale up one of the catalysts developed, from a gram at laboratory scale to multiple kilograms for the demonstration unit;
- to develop a breakthrough integrated system in which the reactor is thermally coupled to a solid oxide fuel cell, simplifying the dehydrogenation plant and improving its thermal efficiency;
- to demonstrate the feasibility of producing H_2 and generating renewable electricity from LOHC-stored hydrogen by heat integration between endothermic hydrogen release and exothermic fuel cell operation.

NON-QUANTITATIVE OBJECTIVES

- To reduce capital expenditure (i.e. owing to the use of less expensive materials, no chemical reagents and no cleaning cycles, and the extended lifetime of materials) and operational expenditure (i.e. owing to a continuous mode of operation and optimised process controls).
- To decrease the cost of transporting H_2, including by demonstrating the feasibility and cost-effectiveness of using LOHC technologies to transport H_2 from on-shore tanks to on-shore tanks all-inclusive.
- To develop a scale-up plan through techno-economic analysis in order to improve techno-economic viability, to include, in particular, comparisons with alternative H_2 technologies for long-distance transport.
- To put the EU at the forefront of H_2 technologies, to ensure a competitive and commercial advantage in Europe to incentivise future investments.
- To reduce the environmental impact of H_2 technologies, by reducing the use and release of toxic substances and CRMs with a huge environmental impact.
- To contribute to the European Green Deal goals through developing a fully CO_2-free dehydrogenation system.

PROGRESS AND MAIN ACHIEVEMENTS

After the first year of the project, we are in the middle of developing CRM-free and low-CRM catalysts; so far, we have created catalysts with conversion rates, selectivity and productivities close to those of the SOA catalysts.

FUTURE STEPS AND PLANS

- Continue developing catalysts at a laboratory scale to improve their conversion, selectivity and productivity, but mainly their stability, in order to reach the project's targets.
- Start designing the reactor to be integrated in the dehydrogenation unit.

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	KPI 1: grade of conversion of CRM-free or low-CRM catalysts	%	95	86		85	2022
	KPI 2: catalyst selectivity	%	> 99.8	98.8		82	2022
	KPI 3: catalyst productivity in dehydrogenation	gH_2/gcat/min	> 0.02	8		0.0212	2022

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HYLICAL

DEVELOPMENT AND VALIDATION OF A NEW MAGNETOCALORIC HIGH-PERFORMANCE HYDROGEN LIQUEFIER PROTOTYPE

Project ID	101101461
PRR 2024	Pillar 2 – H_2 storage and distribution
Call topic	HORIZON-JTI-CLEANH2-2022-02-03: Validation of a high-performance hydrogen liquefier
Project total cost	EUR 4 677 848.75
Clean H_2 JU max. contribution	EUR 4 677 848.75
Project period	1.1.2023–31.12.2027
Coordinator	Institutt for energiteknikk, Norway
Beneficiaries	Asociatia Energy Policy Group, Danmarks Tekniske Universitet, ENGIE, Fives Cryo, Helmholtz-Zentrum Dresden-Rossendorf EV, Iberdrola Clientes SA, Magnotherm Solutions GmbH, Shell Global Solutions International BV, SUBRA A/S, Technische Universität Darmstadt, Universidad de Sevilla, Università di Pisa, Universityof European Parliament and Council of the European Union

https://www.hylical.eu

PROJECT AND GENERAL OBJECTIVES

Hylical will contribute to (i) reaching an energy demand of 8 kWh/kg and a reduction in liquefaction cost of 20 % for small liquefaction volumes of 1–5 t/day; (ii) reducing capital expenditure and operating expenditure by at least 20 % in addition to the targeted energy savings; (iii) decentralising the (local) production of liquid hydrogen (LH_2), thus reducing the need for distribution and transport across long distances; (iv) coupling magnetocaloric hydrogen liquefaction (MCHL) technology to hydrogen production from renewables (green hydrogen) for off-grid configurations; (v) integrating into conventional liquefaction plants to increase their overall energy efficiency; and (vi) applying the processes for the liquefaction of hydrogen and for the management of boil-off from LH_2 tanks.

NON-QUANTITATIVE OBJECTIVES

Hylical aims to provide an alternative solution to the conventional vapour compression technology that offers several advantages.

- Reduced complexity will lead to less risk of failure, reduced requirement for regular maintenance and less downtime.
- The MCHL technology developed will be less noisy and will suffer significantly less from the 'economy of scale' than the currently employed vapour compression technology. It will also be more adaptable to fluctuations in loads and demands.

PROGRESS AND MAIN ACHIEVEMENTS

- Prediction of new materials/compositions for MCHL.
- Updated state of the art (SOA) for LH_2 safety provisions.
- Performance of initial simulations for heat transfer in an active magnetic regenerator (AMR) in cryogenic conditions.
- Starting construction of a cryochamber to host the AMR and testing heat transfer and pressure drops in ambient conditions.

FUTURE STEPS AND PLANS

- Synthesis of promising new materials predicted by computational material design.
- Characterisation of magnetic/structural properties and optimisation of materials for targeted applications.
- Upscaling of material production from grams to kilograms to suit the needs of the planned demonstration.
- Detailed simulation of heat flow, inleak and losses in cryogenic conditions.
- Testing of a cryochamber hosting the AMR and assessment of its properties in cryogenic conditions.

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 SRIA (2021–2027)	H_2 liquefaction energy intensity	kWh/kg	8		10	2020
SRIA (2021– 2027)	H_2 liquefaction cost	€/kg	< 1.5		1.5	2020

LH2CRAFT

SAFE AND EFFICIENT MARINE TRANSPORTATION OF LIQUID HYDROGEN

Project ID	101111972
PRR 2024	Pillar 2 – H_2 storage and distribution
Call topic	HORIZON-JTI-CLEANH2-2022-02-06: Development of large scale LH_2 containment for shipping
Project total cost	EUR 5 627 595.94
Clean H_2 JU max. contribution	EUR 5 627 595.94
Project period	1.6.2023–31.5.2027
Coordinator	Hydrus Anotati Synektiki Michaniki Etaireia Symvoulon Anonymi Etaireia, Greece
Beneficiaries	American Mpiro of Siping Hellenic Monoprosopi Etaireia Periorismenis Evthinis, Bureau Veritas Marine & Offshore – registre international de classification de navires et de plateformes offshore, Cegelec NDT-PSC, EASN Technology Innovation Services BVBA, Ethnicon Metsovion Polytechnion, Foundation Wegemt – A European Association of Universities in Marine Technology and Related Sciences, Gabadi SL, HD Korea Shipbuilding & Offshore Engineering Co., Ltd, Panepistimio Patron, RINA Services SpA, Technische Universität Dresden, TWI Limited, University of Strathclyde

https://lh2craft.eu/

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
SRIA (2021–2027)	LH_2 ship tank CAPEX	€/kg	< 10	
	Boil-off	%/day	< 0.5	
	LH_2 ship tank capacity	t	2 900 per tank	

ANDREAH

AMMONIA BASED MEMBRANE REACTOR FOR GREEN HYDROGEN PRODUCTION

Project ID	101112118
PRR 2024	Pillar 2 – H_2 storage and distribution
Call topic	HORIZON-JTI-CLEANH2-2022-02-04: Ammonia to green hydrogen: efficient system for ammonia cracking for application to long distance transportations
Project total cost	EUR 2 980 361.25
Clean H_2 JU max. contribution	EUR 2 980 361.25
Project period	1.7.2023–30.6.2027
Coordinator	Fundacion Tecnalia Research and Innovation, Spain
Beneficiaries	1 Cube BV, Consiglio Nazionale delle Ricerche, Iberdrola Clientes SA, KIC InnoEnergy SE, RINA Consulting SpA, Technische Universiteit Eindhoven, Umicore Denmark ApS, VTTI BV

https://www.andreahproject.eu/

PROJECT AND GENERAL OBJECTIVES

The Andreah Horizon Europe project aims to effect a quantum leap in the development of advanced ammonia decomposition technologies to produce ultra-pure hydrogen (> 99.998 %) by developing an innovative system based on a catalytic membrane reactor for the cracking of ammonia.

The system will be based on the design, construction and testing of an advanced ammonia cracker for ultra-pure hydrogen production (10 kgH_2/day) based on a catalytic membrane reactor in order to intensify the process of hydrogen production through the integration of cracking and purification. The advance cracker will include:

- an innovative and environmentally friendly structured catalyst constructed with few critical materials that can be used at much lower temperatures than in the state-of-the-art (SOA) process;
- innovative membranes for the selective separation of H_2 during the production process.

The project will also involve developing novel sorbents for polishing the H_2 recovered by the membranes. In addition, it will include the design and optimisation of all the subcomponents of the balance of plant with particular attention to optimising thermal integration.

NON-QUANTITATIVE OBJECTIVES

- Designing and setting up a broad and complete network of value chains with world-class universities, research centres and industrial partners to develop the key building blocks for ammonia cracking.
- Developing a full life-cycle assessment, life-cycle costing and health and safety analysis of Andreah.
- Developing a set of flexible, cost-effective and environmentally friendly technologies that can be easily tailored for the decomposition of ammonia into green H_2 for different applications (energy, transport, etc.).
- Paving the way for the future exploitation of Andreah's key exploitable results, by laying the foundations for new business opportunities related to the development of new catalysts and membranes integrated into membrane reactors to provide huge process intensification, enabling the distributed generation of hydrogen from NH_3 as a long-term storage media.
- Promoting the dissemination and communication of Andreah's results and expanding its impact.

FUTURE STEPS AND PLANS

- Conduct of a market and stakeholder analysis.
- Development of a novel catalyst and structured catalyst for application onto open cell foams and 3D-printed periodic open cellular structures and catalyst kinetic modelling.
- Development of sorbents for sorbent kinetics sorption modelling.
- Development of carbon molecular sieve membranes selective for H_2 in an H_2, N_2 and NH_3 mixture and membrane modelling.
- Conduct of a preliminary integrated analysis of the new technologies based on sustainability pillars and circularity analysis, including a preliminary life-cycle assessment, life-cycle costing and a social life-cycle assessment.

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	Amount of Pd per membrane	g	< 0.1		2.6	2023
	OPEX of the ammonia-cracking system	k € / year	209.5		282.42	2020
	Decentralised cost of H_2 production	€/kg	4.27		5.51	2020
	Amount of Ru in the catalyst for low-temperature (< 500 °C) cracking	wt%	< 1		2–8	2021
	CAPEX of the ammonia-cracking system	k €	211.74		384.72	2020
SRIA (2021–2027)	H_2-carrier-specific energy consumption	kWh input / kgH_2 recovered	16		20	2020

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SINGLE

ELECTRIFIED SINGLE STAGE AMMONIA CRACKING TO COMPRESSED HYDROGEN

Project ID	101112144
PRR 2024	Pillar 2 – H_2 storage and distribution
Call topic	HORIZON-JTI-CLEANH2-2022-02-04: Ammonia to green hydrogen: efficient system for ammonia cracking for application to long distance transportations
Project total cost	EUR 2 989 671.25
Clean H_2 JU max. contribution	EUR 2 989 671.25
Project period	1.5.2023–30.4.2026
Coordinator	CoorsTek Membrane Sciences AS, Norway
Beneficiaries	Consejo Superior de Investigaciones Científicas, Fondazione ICONS, Gea Energia Crio SL, SINTEF AS, Universitat Politècnica de Catalunya, Univerza v Ljubljani

https://singleh2.eu/

PROJECT AND GENERAL OBJECTIVES

Single will enable ammonia to be used as an energy carrier in the hydrogen value chain through the demonstration of a proton ceramic electrochemical reactor that integrates the ammonia dehydrogenation reaction, hydrogen separation, heat management and compression in a single stage. The combination of the four steps in a single reactor allows the technology to achieve unprecedented energy efficiencies and deliver purified, pressurised hydrogen (20 bar). Single will demonstrate the technology at a 10 kgH_2/day scale that will provide a pathway for future scaled-up systems, ranging from small (fuelling stations) to large, centralised (at harbours) structures.

NON-QUANTITATIVE OBJECTIVES

Single aims to disseminate information to relevant communities and maximise the outcomes and reach of the project.

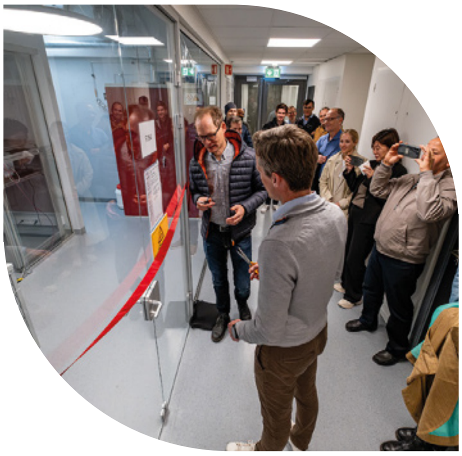
Those involved in implementing the project collaborate with standardisation organisations to valorise project results by contributing to the creation or revision of standards. To achieve this goal, Single has used HSbooster.eu's consultancy services to guide the project consortium to ensure the adoption of the right strategic approach and efficient contribution to the standardisation process.

PROGRESS AND MAIN ACHIEVEMENTS

- Ni and barium zirconium yttrium cerate support catalytic activity, and their stability has been studied to enable optimisation by infiltrating the active metal and changing the morphology of Ni and its interaction with the barium zirconium yttrium cerate support.
- Candidate alloy materials have been identified for constructing and safely operating reactor housing in the presence of ammonia.
- Cells, KETs and stacks have been manufactured.
- Single collaborated with Hsbooster.eu for 3 months to perform standardisation activities.

FUTURE STEPS AND PLANS

- The proton ceramic electrochemical reactor cell will be further optimised to improve its catalytic activity and electrochemical performance under relevant conditions.
- Stacks for 10 kgH_2/day module will be fabricated.
- The 10 kgH_2/day module will be designed, assembled, constructed and tested.
- The life cycle, value chain economics and critical raw materials of the system will be assessed.



PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?	SOA result achieved to date (by others)
SRIA (2021–2027)	Hydrogen-carrier-specific energy consumption	kWh input / kgH_2 recovered	17		20
	Hydrogen carrier delivery cost (for 3 000 km ship transfer)	€/kg	2.5		4

WINNER

WORLD CLASS INNOVATIVE NOVEL NANOSCALE OPTIMIZED ELECTRODES AND ELECTROLYTES FOR ELECTROCHEMICAL REACTIONS

Project ID	101007165
PRR 2024	Pillar 2 – H_2 storage and distribution
Call topic	FCH-03-1-2020: HT proton conducting ceramic materials for highly efficient and flexible operation
Project total cost	EUR 2 931 788.75
Clean H_2 JU max. contribution	EUR 2 931 788.75
Project period	1.1.2021–31.3.2024
Coordinator	SINTEF AS, Norway
Beneficiaries	Consejo Superior de Investigaciones Científicas, Alleima Tube AB, CoorsTek Membrane Sciences AS, Danmarks Tekniske Universitet, ENGIE, Shell Global Solutions International BV, Universitetet i Oslo

https://www.sintef.no/projectweb/winner/

PROJECT AND GENERAL OBJECTIVES

The Winner project is contributing to the shift towards a future with more sustainable energy by developing an efficient and durable technology platform based on electrochemical proton ceramic conducting (PCC) cells designed to unlock a path towards commercially viable production, extraction, purification and compression of hydrogen at a small to medium scale through three process chains:

- cracking of ammonia to produce pressurised hydrogen or power, where PCC reactors provide an innovative solution for the flexible, secure and profitable storage and utilisation of energy in the form of green ammonia;
- dehydrogenation of ethane to produce ethylene and pressurised hydrogen, where PCCRs provide new sustainable pathways for electrically driven processes in the chemical industry;
- reversible steam electrolysis (using reversible protonic ceramic electrochemical cells), where PCC reactors allow the shifting of electric power generation to hydrogen production, enabling grid balancing, improved matching of the demand and supply of electricity, and more efficient use of renewable energy sources.

NON-QUANTITATIVE OBJECTIVES

Winner is developing a multiscale, multiphysics modelling platform integrating various disciplines (atomistic, electrochemical, mechanical, fluid flow, reactor engineering, electric, heat), with the goal of establishing the rate-determing steps at a meso scale in the electrochemical cell, and the most efficient dimensioning and arrangement of the cells in the multitube reactor design. The work is supported by relevant experimental data and enhanced experimentation methodologies applied in the project.

PROGRESS AND MAIN ACHIEVEMENTS

The project developed novel tubular cells using a production line established by CoorsTek Membrane Sciences, consisting of a Ni-BZCY72 electrode with BZCY81-dense electrolyte. The cells met performance criteria for reversible electrolysis of ammonia to hydrogen cells, with a cell area-specific resistance below 1 ohm.cm^2 at 650 °C, a faradaic efficiency of 80–90 % and a degradation rate below 1.2 %/kh under reversible operation. A tubular cell was successfully in reversible operation for over 4 000 h at 4 bar at 650 °C. The results of these research and development activities are reported in several public deliverables. A communication platform was established to link various models and competencies developed from the atomistic scale to the process scale. An engineering model was created for each of the Winner applications, which is now functioning alongside multiple other models integrated together. The construction of a computational fluid dynamics model has been initiated, with outputs including energy demand in relation to balance of plant and for the overall process for selected input parameters. A life-cycle assessment of three applications was conducted, showing the benefits of proton ceramic technologies in comparison with benchmark cases. In 2023, a multitube testing unit within Consejo Superior de Investigaciones Científicas was prepared, and upgrades and commissioning were initiated.

FUTURE STEPS AND PLANS

The project was finalised at the end of March 2024 with the delivery of techno-economic analysis and life-cycle assessment results. A results exploitation workshop was also organised in March 2024.

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	Round-trip efficiency of reversible steam electrolysis	% at 650 °C	> 75	N/A		Unclear as this is not well documented in the literature	2019
	Faradaic efficiency	%	> 95	> 90		> 90	2021
	Durability	hours	3 000	> 4 000	✓	< 1 000	2021
	Area-specific resistance of cell	ohm.cm^2 at 650 °C	< 1	< 1		2.5	2022
Project's own objectives and MAWP (2018–2020)	Levelised cost of hydrogen produced	€/kg	5	N/A		> 6, based on GAMER technology with several scaling up assumptions	2022

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HQE

HYQUALITY EUROPE

Project ID	101101447
PRR 2024	Pillar 2 – H_2 storage and distribution
Call topic	HORIZON-JTI-CLEANH2-2022-02-09: Sampling methodology and quality assessment of HRS
Project total cost	EUR 3 453 685.00
Clean H_2 JU max. contribution	EUR 3 453 685.00
Project period	1.1.2023–31.12.2025
Coordinator	SINTEF AS, Norway
Beneficiaries	Air Liquide France Industrie, Deutsches Zentrum für Luft- und Raumfahrt EV, Europäisches Institut für Energieforschung EDF KIT EWIV, EMCEL GmbH, ENGIE, ENGIE Energie Services, L Air Liquide SA, LINDE GmbH, NPL Management Limited, Orlen Laboratorium SA, Toyota Motor Europe NV, Zentrum für BrennstoffzellenTechnik GmbH, Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg

http://hyqualityeurope.eu

PROJECT AND GENERAL OBJECTIVES

The goal of the project is to increase the reliability of hydrogen refuelling stations (HRSs) and the confidence of investors, operators and consumers in them. The project's objectives are to:

- collect representative data on the quality of hydrogen in European HRSs (300 spot samples in 100 HRSs);
- develop an occurrence class and promote an approach involving risk assessment;
- establish an open-source database to compile the results to allow HRS operators to take an approach involving risk assessment to ensure hydrogen quality;
- test a network of six hydrogen analysis laboratories in order to certify them at the EU level;
- demonstrate the effectiveness of online analysis;
- standardise hydrogen quality sampling and analysis methodologies for EU HRSs;
- aid future research by defining the occurrence class of at least four new impurities beyond those listed in EN 17124:2022 and the International Organization for Standardization (ISO) 21087:2019.

PROGRESS AND MAIN ACHIEVEMENTS

The project has extensively contributed to the development of ISO 14687, 19880–9 and 19880–8.

The work to collect information from HRS operators and perform sampling and analysis started. The first laboratory comparison was completed, with nine laboratories taking part. All impurities listed in ISO 14687 were present in the comparison, and this is the first comparison to be conducted of this type.

A hydrogen quality workshop was hosted by ISO, ASTM International and the National Renewable Energy Laboratory to disseminate some of the early results of the project.

FUTURE STEPS AND PLANS

The project will continue the sampling and analysis work, working towards a target of collecting 300 samples. Further laboratory comparisons will be conducted. The project will also install online quality-monitoring facilities in three HRSs.

PROJECT TARGETS

Target source	Parameter	Unit	Achieved to date by the project	Target achieved?
Project's own objectives	Standards affected by project	number	3	

Clean Hydrogen Partnership
Co-funded by the European Union

H2REF-DEMO

HYDRAULIC COMPRESSION FOR HIGH CAPACITY HYDROGEN REFUELLING STATION DEMONSTRATION

Project ID	101101517
PRR 2024	Pillar 2 – H_2 storage and distribution
Call topic	HORIZON-JTI-CLEANH2-2022-02-08: Development of novel or hybrid concepts for reliable, high capacity and energy-efficient H_2 compression systems at real-world scale
Project total cost	EUR 5 786 712.50
Clean H_2 JU max. contribution	EUR 4 617 384.88
Project period	1.1.2023–30.6.2026
Coordinator	Centre technique des industries mécaniques, France
Beneficiaries	Faber Industrie SpA, H2Nova, HYDAC Technology GmbH, Hydrogen Refueling Solutions, Università degli Studi di Modena e Reggio Emilia, Université de Technologie de Compiègne

https://heavy-v.h2ref.eu/about-us/

PROJECT AND GENERAL OBJECTIVES

H2REF-DEMO aims to further develop and quintuple the innovative compression concept developed in H2REF in order to address large vehicle refuelling applications requiring hydrogen to be dispensed at rates of hundreds of kilograms per hour, such as refuelling bus fleets every evening at bus depots, refuelling trucks and refuelling trains. The concept is particularly suited to scaling up, thanks to the scalability of fluid power technology and composite pressure vessel technologies.

As it incorporates the intrinsic modularity of fluid power technology together with that of pressure vessel technology, this disruptive solution will allow the different expected hydrogen supply configurations to be addressed in a cost-effective and reliable manner, in particular those that are the most suitable for large-scale refuelling applications for which daily consumption exceeds 1 t:

- on-site production;
- road delivery with high-pressure trailers (e.g. 500 bar, in carbon composite), as these have an effective payload of around 1 t.

Large-scale hydrogen refuelling involves two distinct types of compression.

- **Compression of hydrogen production for storage.** As production is the supply chain function with the highest cost, it tends to be performed through continuous (24/7) operation of production devices sized on the basis of daily consumption. Storage of the hydrogen produced requires compression at the same rate in order to keep storage size and footprint within acceptable limits.
- **Compression of stored hydrogen for high-capacity dispensing.** This compression function brings hydrogen from storage – that is, a fixed vessel storing hydrogen produced on site, a fixed vessel into which hydrogen has been delivered by trailer or a trailer – maintaining the pressure required for dispensing at the rate required when dispensing takes place, for example at any time of the day when vehicles pull in to refuel, or almost continuously during a certain time frame (e.g. 4–6 h per day at a bus depot). The feed pressure of compression for dispensing is typically higher than that of compression for storage; however, the required throughput is also higher (as dispensing takes place only part of the time).

NON-QUANTITATIVE OBJECTIVES

The main goal of the project is to develop and test at full scale a high-capacity compression module (HCCM) capable of either hydrogen compression for storage prior to dispensing (1.2 t/day) or hydrogen compression for high-capacity (35 MPa) dispensing (150 kg/h–2.5 kg/min), with 1 year's demonstration of use for the high-capacity refuelling of heavy-duty vehicles in a commercially operated refuelling station. Particular attention will be given to optimising design to minimise costs.

PROGRESS AND MAIN ACHIEVEMENTS

In the first year of the H2REF-DEMO project, the following results were achieved:

- multiphysical modelling and simulation of the HCCM process and initial sizing and estimation of potential performance;
- functional specification of the HCCM based on a bladder accumulator and an elementary compression unit;
- functional specification and material selection for bladder and tests on material;
- design of the shell of the accumulator;
- development of an initial safety plan;
- specification and simulation of the global refuelling system;
- specification and simulation of the hydraulic power pack;
- review of existing regulations, codes and standards and identification of gaps with the project activities.

FUTURE STEPS AND PLANS

- Selection of bladder material / manufacture of bladders.
- Manufacture of shells.
- Development of the accumulator and performance of the first tests.
- Development of the hydraulic power pack.
- Start of the development of the gas skid.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	CAPEX	k€/(kg/day)	3.5	
	Availability	%	97	
	Mean energy to 350 bar	kWh/kg	3.5	
	MTBF	days	47	
	HRS contribution to H_2 price	€/kg	2.5	
	Bladder durability	cycles	20 000	

Clean Hydrogen Partnership
Co-funded by the European Union

HYGHER

HYDROGEN HIGH PRESSURE SUPPLY CHAIN FOR INNOVATIVE AND COST EFFICIENT DISTRIBUTION

Project ID	101137867
PRR 2024	Pillar 2 – H_2 storage and distribution
Call topic	HORIZON-JTI-CLEANH2–2023-02-04: Demonstration of high pressure (500–700 bar) supply chain
Project total cost	EUR 6 769 096.25
Clean H_2 JU max. contribution	EUR 4 991 009.88
Project period	1.1.2024–31.12.2026
Coordinator	Europäisches Institut für Energieforschung EDF KIT EWIV, Germany
Beneficiaries	EIFHYTEC, Fraunhofer-Gesellschaft zur Förderung der Angewandten Forschung EV, Hype, Hype Assets, RE.CO.MA SRL, Steinbeis Innovation gGmbH, Univerza v Ljubljani

https://cordis.europa.eu/project/id/101137867/fr

PROJECT AND GENERAL OBJECTIVES

Hygher is an EU project funded by the Clean Hydrogen Partnership and coordinated by the European Institute for Energy Research (in Germany). It aims to demonstrate the maturity of an innovative high-pressure hydrogen distribution value chain. This will include the installation of an innovative filling centre able to compress hydrogen at high pressure, and the operation of two new high-pressure trailers to supply the fleet of taxis operated by HYPE in Île-de-France. With a total budget of over EUR 6.7 million, the seven consortium partners are working on improving and integrating all components along the new value chain. Through specific efforts on innovative compression, circularity and safety, the project will allow sustainable and cost-efficient hydrogen distribution, removing one of the main barriers to the wider deployment of hydrogen mobility. The project started in 2024 and has an expected duration of 3 years.

NON-QUANTITATIVE OBJECTIVES

The main objective of Hygher is to demonstrate the feasibility of an innovative, cost-efficient and reliable high-pressure value chain, by combining various innovative technologies ready for large-scale demonstration.

The main progress expected beyond the state of the art (SOA) and the results of Hygher is as follows:

- build an innovative filling centre equipped with a metal hydride compressor, a mechanical booster and cascade storage, enabling the efficient distribution of > 2 t/day at 500 bar;
- build two innovative trailers, with a capacity of 1.25 t of hydrogen each at an operating pressure of 500 bar, equipped with innovative control, monitoring and communication devices to ensure efficiency and interoperability;
- adapt a standard hydrogen refuelling station by integrating 500-bar trailers into smart storage cascade management and thereby significantly improve efficiency and demonstrate a capacity increase;
- install and operate the overall value chain in Île-de-France, close to trans-European transport network corridors, and thus reinforce the EU H_2 infrastructure network and prepare for its replication and massification;
- demonstrate the new value chain under real commercial conditions, by operating the equipment with HYPE's fleet of fuel cell electric vehicles (taxis) and other 350-bar and 700-bar fuel cell electric vehicles;
- validate the safety of the overall concept at 500 bar and prepare for a 700-bar upgrade by screening the framework of regulations, codes and standards, and performing safety analyses of parts of the system, from single components to the overarching value chain.

FUTURE STEPS AND PLANS

The main first steps of the project to be conducted in 2024 are:

- the preparation of the initial project safety plan, including a review of the regulations, codes and standards, and the planning of safety studies for individual systems and for the demonstration;
- the setting of specifications at the value chain level and determination of the optimised design of subsystems;
- the preparation of the construction phase of all subsystems (ordering components and planning construction in workshops);
- the definition of scenarios and collection of existing data for a techno-economic assessment study, life-cycle analysis and scale-up analysis;
- the preparation of the promotional toolbox, launch of the communication campaign, determination of the initial exploitation and intellectual property strategy, the delivery of a webinar for experts and stakeholders to introduce them to the project and the validation of techno-economic specifications.

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	Trailers filled at high pressure (500–700 bar)	number	2		N/A	N/A
	Filling centres at high pressure (500–700 bar)	t/day	2.15		N/A	N/A
	HRS quantities delivered	kg/day	2 500 in 2 HRSs		N/A	N/A
SRIA (2021–2027)	Tube trailer CAPEX	€/kg	450		650	2 000
	Operating pressure of tube trailer	bar	500		300	2 000
	Tube trailer payload	kg	1 250		850	2 000

COSMHYC DEMO

COMBINED SOLUTION OF METAL HYDRIDE AND MECHANICAL COMPRESSORS: DEMONSTRATION IN THE HYSOPARC GREEN H_2 MOBILITY PROJECT

Project ID	101007173
PRR 2024	Pillar 2 – H_2 storage and distribution
Call topic	FCH-01-8-2020: Scale-up and demonstration of innovative hydrogen compressor technology for full-scale hydrogen refuelling station
Project total cost	EUR 3 773 858.75
Clean H_2 JU max. contribution	EUR 2 999 637.13
Project period	1.1.2021–31.12.2024
Coordinator	Europäisches Institut für Energieforschung EDF KIT EWIV, Germany
Beneficiaries	Communauté de Communes Touraine Vallée de l'Indre, EIFHYTEC, MAHYTEC SARL, Nel Hydrogen AS, Steinbeis Innovation gGmbH

https://cosmhyc.eu

PROJECT AND GENERAL OBJECTIVES

To meet the demands of a growing hydrogen economy, new technologies in the hydrogen refuelling infrastructure – including those for hydrogen compression – are necessary. In Cosmhyc DEMO, the innovative Cosmhyc compression solution, which combines a metal hydride and mechanical compressor, has been shown to be ready for commercial deployment. At the test site in France, a public hydrogen refuelling station (HRS) will be installed for a variety of vehicles (e.g. fleet vehicles and garbage trucks). The hybrid compressor will be used to supply hydrogen at both 350 bar and 700 bar.

NON-QUANTITATIVE OBJECTIVES

- The project aims to increase public acceptance of hydrogen mobility. Integrating the new compressor in a community in which there have been previous hydrogen mobility activities and demonstration projects is likely to increase overall acceptance.
- It also aims to include a smart gas hub for switching between storage, the HRS and the filling centre. A new gas panel has been designed and will allow for smart switching between the filling centre for trailers, on-site hydrogen supply storage and the HRS.

PROGRESS AND MAIN ACHIEVEMENTS

The main achievement is the installation of the new HRS on the demonstration site and the start of refuelling operations, mainly involving the garbage truck of Interreg North-West Europe's Hector project.

Other major areas of progress and achievements are as follows:

- A new membrane mechanical compressor was designed and manufactured. In addition, the design of an innovative metal hydride compressor was set and its assembly and certification process is in the advanced stages.
- The compositions of the metal hydrides for all stages of compression were selected, without rare earth materials. These hydrides are currently produced in high quantities (approximately 1 000 kg per compression stage). Furthermore, compressive reactors have been manufactured, including a brand new heat exchanger specifically developed as part of the project.
- Significant progress has been made in the permit-issuing process related to the installation of the metal hydride compressor on the demonstration site.
- The filling centre gas panel was completed, involving safety studies. The Communauté de Communes Touraine Vallée de l'Indre refuelling demonstration site will also be capable of green hydrogen production, funded as part of the Hy'Touraine initiative. The Cosmhyc DEMO metal hydride compressor and filling centre gas panel will also be used to compress hydrogen produced at Hysoparc.

FUTURE STEPS AND PLANS

- The refuelling operations are starting at the newly built HRS at the demonstration site in Sorigny, France.
- The integration of a metal hydride compressor is planned for mid 2024.
- Long-term tests of the demonstration unit will be conducted with the on-site vehicle fleet.
- Final exchanges about safety studies and authorisation are taking place.
- An opening event for the launch of the HRS and compressor will be organised to gather local stakeholders and the general public, including EU officials, at the demonstration site.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Nominal pressure of the on-site storage tank	bar	950	
	Storage capacity	kg	125	
	Refuelling protocol	–	SAE J2601 (light-duty vehicles) SAE J2601–2 (heavy-duty vehicles)	
	Noise	dBA	60	
	Daily capacity	kg/day	200	
	Dispensing pressure	bar	200/350/700	✓

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RHEADHY

REFUELLING HEAVY DUTY WITH VERY HIGH FLOW HYDROGEN

Project ID	101101443
PRR 2024	Pillar 2 – H_2 storage and distribution
Call topic	HORIZON-JTI-CLEANH2-2022-02-10: Implementing new/optimised refuelling protocols and components for high flow HRS
Project total cost	EUR 4 734 730.00
Clean H_2 JU max. contribution	EUR 3 999 381.50
Project period	1.2.2023–31.1.2027
Coordinator	ENGIE, France
Beneficiaries	Alfa Laval Vicarb SAS, Benkei, Emerson Process Management Flow BV, ENGIE Energie Services, Faurecia Systèmes d'Echappement SAS, Hydrogen Refueling Solutions, Lauda DR. R. Wobser GmbH & Co. KG, Tescom Europe GmbH & Co. KG, Zentrum für BrennstoffzellenTechnik GmbH

https://rheadhy.eu/

PROJECT AND GENERAL OBJECTIVES

Rheadhy's main goal is to develop components and refuelling stations able to fully implement and test new – very-high-flow – refuelling protocols for heavy-duty vehicles and bring them to the market.

NON-QUANTITATIVE OBJECTIVES

- **Design and assemble a very-high-flow hydrogen refuelling line.** The main goal is to provide components and refuelling lines designed for the required performance and operating conditions (very high flow rate, pressure, temperature, dynamic behaviour), with optimal trade-off between constraints and performance and constraint repartitioning among components.
- **Develop new components needed for high-flow refuelling.** The main goals are to develop new very-high-flow components and make them ready to commercialise (cooling technology, flow meters, valves, heat exchangers), to develop an advanced bidirectional communication interface, and to test, optimise and adapt components already in the prototype phase of their development (breakaway, hose, nozzle and receptable assembly).
- **Develop and demonstrate a new protocol for refilling storage systems.** The main goal is to demonstrate new standardised refuelling protocols for heavy-duty vehicles developed in ISO TC 197 WG24 or by other standardisation bodies.
- **Ensure the fast and efficient refilling of storage systems with H_2 at a low cost.**
- **Standardise and certify components of hydrogen refuelling stations to ensure the fast deployment of the components.** The main goals are to contribute to the development of standards through participation in the development of ISO TC 197 and CEN 268 WG5 and to obtain certifications for all the components in accordance with the relevant standards (ISO TC 197, CEN 268 WG5, OIML R139).

PROGRESS AND MAIN ACHIEVEMENTS

- All partners (product manufacturers) have completed the design of the concept for their product (including mechanical design, electrical design, communication, first 3D model, first draft of piping and instrumentation diagram or layout, etc.) and are now starting the detailed design phase.
- More than 250 simulations have already been done in order to aid the design of the different components.

FUTURE STEPS AND PLANS

The components for the Rheadhy project (cooling unit, by Lauda; heat exchanger, by Alfa Laval; flow sensor, by Emerson Micro Motion; control valve and safety valves, by Emerson Tescom; transport storage testing system, by Forvia) will be developed.

Then, the high-flow distribution line will be integrated into two hydrogen refuelling stations (the Hydrogen Refueling Solutions site and the ZBT site).

Afterward, tests will be performed on these two stations in order to validate the key performance indicators of the project.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Time to refill a 100 kg HD truck storage test system	minutes	10	
	Time to refuel a heat exchanger and cooling system for hydrogen dispensed below – 30 °C	minutes	10	
	Pressure regulator and shut-off valve compatible with very high flow rate and high pressure (1 000 bar)	g/s	170 (mean flow rate); 300 (peak flow rate)	
	Peak flow for prototype's breakaway, nozzle and hose	g/s	300	
	Refuelling events demonstrated for the fully integrated chain	number	300	
	Refuelling simulations performed	operations	1 000	
	Flow rate determined by measuring device compatible with very high flow rate, targeting > 100 kg total mass per refuelling	g/s	170 (mean flow rate); 300 (peak flow rate)	

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DELHYVEHR

DELIVERY OF LIQUID HYDROGEN FOR VARIOUS ENVIRONMENT AT HIGH RATE

Project ID	101137743
PRR 2024	Pillar 2 – H_2 storage and distribution
Call topic	HORIZON-JTI-CLEANH2-2023-02-05: Demonstration of LH_2 HRS for heavy duty applications
Project total cost	EUR 5 064 971.25
Clean H_2 JU max. contribution	EUR 3 711 901.13
Project period	1.1.2024–31.12.2026
Coordinator	ENGIE, France
Beneficiaries	Absolut System SAS, ArianeGroup SAS, Asociatia Energy Policy Group, Benkei, Cesame-Exadébit SA, DEKRA Services SA, Elengy SA, European Research Institute for Gas and Energy Innovation, Fives Cryomec AG, Trelleborg Clermont-Ferrand SAS, Trelleborg Sealing Solutions UK Limited, University of Ulster

https://cordis.europa.eu/project/id/101137743

PROJECT AND GENERAL OBJECTIVES

The European research project Delhyvehr, coordinated by ENGIE, will develop a liquid hydrogen (LH_2) high-rate bunkering station with a refuelling flow rate of > 5 TPH and zero boil-off losses, dedicated to maritime, aviation and railway applications. The project is expected to complete its demonstration by 2026. Along with market maturity, the cost of distribution is expected to be halved by 2030.

Delhyvehr will drive the maturation of each main system constituting the large-scale refuelling station, with a specific focus on pumping (Fives Cryomec AG), metering (Cesame-Exadébit SA), loading (Trelleborg) and boil-off gas management systems (Absolut System SAS) of the full demonstration apparatus (ArianeGroup SAS). Throughout the project, H_2 safety management activities (University of Ulster) will support the maturation plan and de-risk design and operation. Technology, economic and environmental (policy and governance) studies will allow the assessment and replication of the performance of the demonstration.

NON-QUANTITATIVE OBJECTIVES

- Facilitate the industrialisation of high-rate refuelling station for aviation, maritime and railway applications.
- Reduce helium consumption, which may be a showstopper in LH_2 development, by using gaseous nitrogen for sanitation.
- Provide harmonised guidelines and recommendations for the deployment of bunkering stations.
- Decarbonise heavy-duty vehicle transport and dedicated infrastructure to deliver a hydrogen-related carbon footprint aligned with the second edition of the renewable energy directive (less than 3.38kgCO_2/kgH_2).

FUTURE STEPS AND PLANS

The project will first define the high-level requirements of each application based on a functional design analysis with the support of end users from the advisory board.

Through modelling, design, manufacturing and functional testing, the project will increase the technological maturity of each key component of the refuelling line in a dedicated track.

Those developments will feed into the integrated design and associated protocols specification to form components that can be assembled into a demonstration unit built at ArianeGroup SAS's unique European facility in Vernon, France.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	LH_2 flowmeter calibration uncertainty on the mass flow rate	wt%	0.8	⚙
	Flow rate at which liquid hydrogen is delivered	kg/h	5 000	✓
	Cryogenic pump design's hydraulic efficiency	%	45	⚙

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ROAD TRHYP

ROAD TRAILER DESIGN: USE OF TYPE V THERMOPLASTIC TUBE WITH LIGHT COMPOSITE STRUCTURE FOR HYDROGEN TRANSPORT

Project ID	101101422
PRR 2024	Pillar 2 – H_2 storage and distribution
Call topic	HORIZON-JTI-CLEANH2-2022-02-07: Increased hydrogen capacity of GH 2 road trailers
Project total cost	EUR 2 642 912.59
Clean H_2 JU max. contribution	EUR 2 499 999.50
Project period	1.1.2023–31.12.2025
Coordinator	Air Liquide SA, France
Beneficiaries	Arkema France SA, Centre national de la recherche scientifique, Covess NV, École Nationale Supérieure de Mécanique et d'Aérotechnique, Efectis France, Envitest J. Pacholski Sp J, Politechnika Wrocławska, Segula Engineering, Segula Slovensko s.r.o., Université de Poitiers

http://road-trhyp.eu/

PROJECT AND GENERAL OBJECTIVES

The overall ambition of the ROAD TRHYP project is to demonstrate that using a trailer made out of thermoplastic composite tubes (type V) is a suitable solution to maximise the amount and the quantity of H_2 transported while satisfying end-user requirements (safety, ability to be decontaminated) and enforced regulations with a low TCO.

The main objectives are to:

- design type V 700-bar tubes according to EN 17339 and key performance tests;
- elaborate a decontamination methodology to ensure H_2 purity;
- demonstrate the safety of type V tubes;
- demonstrate that a trailer made with type V tubes will achieve the expected key performance indicators in 2030 and improved environmental impact;
- formulate the regulatory recommendations aimed at accelerating the deployment of the technology.

PROGRESS AND MAIN ACHIEVEMENTS

- Type V cylinders have been developed and preliminary testing is ongoing.
- Raw material to be processed to make type V cylinders has been developed and optimised with a carbon fibre content of 57 % by volume.
- The methodology for carrying out a design of experiments analysis and the bench test to enable testing to find the optimised parameters for a type V cylinder are ready.
- A safety study has shown that the three main accident scenarios for a trailer are hose rupture, leakage of the filling hose and leakage of the piping. An assessment of the severity of H_2 flammable cloud ignition consequences in the case of no mitigation measures has been carried out.
- The initial trailer design work done so far has shown that the target of 1.5 t of H_2 stored in a trailer is achievable.
- An assessment of the regulation of H_2 cylinders and ancillary components, H_2 fuelling stations and H_2 transport has been carried out.
- Life-cycle analyses carried out on a type I and a type IV trailer show that there is a benefit in terms of reducing CO_2 emissions, the use of fossil and mineral resources, and particle emission, among other things.

FUTURE STEPS AND PLANS

The next steps are:

- finalise preliminary type V cylinder testing;
- carry out decontamination tests on one cylinder;
- start ambient extreme temperature cycling tests and bonfire tests;
- conduct permeation tests;
- recommend regulations for operating trailers with type V cylinders in hydrogen refuelling stations;
- determine barriers to the safe operation of a trailer with type V cylinders;
- determine thermophysical properties of the processed material and study the mechanical behaviour of the cylinder in response to fire;
- finalise the trailer design and design a demonstration unit;
- manufacture the demonstration unit;
- model temperature when filling and defueling, then fill and defuel the demonstration unit to calibrate the prediction tool developed;
- carry out a bonfire test on a demonstration unit to simulate the behaviour in response to fire of a cylinder and a set of cylinders;
- finalise the life-cycle assessment with a trailer equipped with type V cylinders;
- assess the TCO.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Operating pressure	bar	700	
	Tube trailer payload	kg	1 500	
	Tube trailer CAPEX	€/kg	400	

III. PILLAR 3 – H2 END-USES: TRANSPORT APPLICATIONS

OBJECTIVES: Pillar 3 encompasses both research projects and demonstration initiatives and is divided into seven research areas: building blocks, aviation, HDVs, waterborne applications, rail applications, buses and coaches, and cars. The Clean Hydrogen JU's SRIA identifies KPIs and quantitative targets for FC building blocks, on-board hydrogen storage, maritime, trains and aviation. The pillar is divided into seven research areas, as described below.

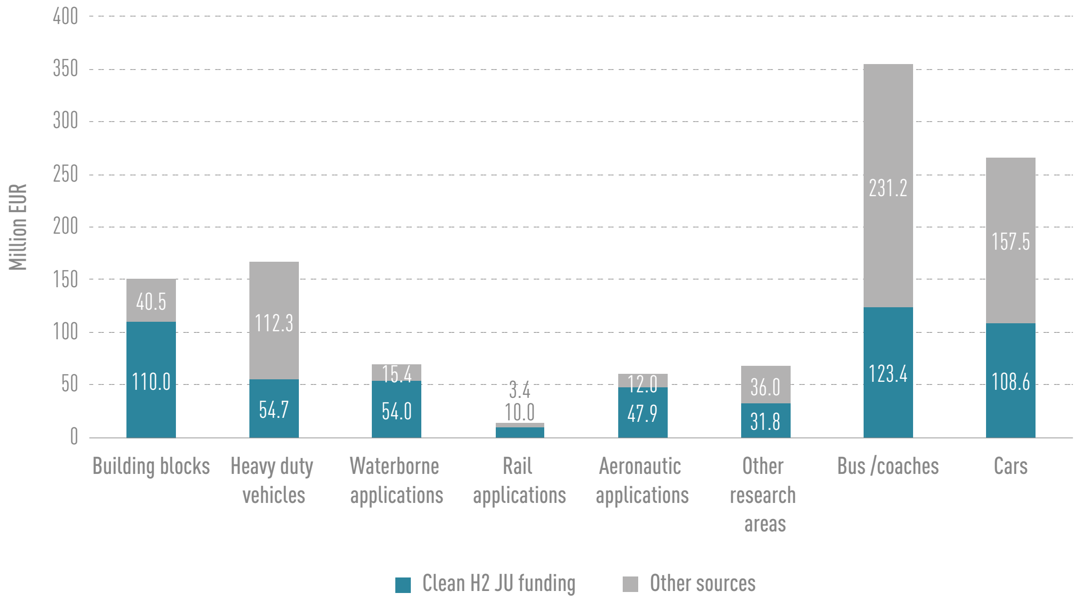
- **Building blocks** focuses on material design and system optimisation for both LT and HT PEMFCs. It contains, in the 2024 programme technical assessment, 11 R&I projects on FC system technology and 1 project on on-board compressed hydrogen storage.
- **Heavy-duty vehicles** addresses optimisation of BoP architectures to meet HDV needs and covers, for the 2024 programme technical assessment, 3 demonstration projects for heavy-duty trucks.
- **Waterborne applications** focuses on improving access to the market for hydrogen, its derivatives and FCs, including large-scale demonstrations. The 2024 programme technical assessment contains 5 demonstration actions.
- **Rail applications** has the objective of enabling hydrogen to be recognised as the leading option for trains on non-electrified routes or partially electrified routes. There is just 1 project in this research area.
- **Aeronautic applications** addresses optimisation of BoP components and architecture design to meet aviation needs. The 2024 programme technical assessment contains 4 projects on FC demonstration for aeronautic applications and 1 project on development of a liquified hydrogen storage system integrated in an aircraft.

Demonstration activities of buses and vehicles are focused on:

- **Bus and coaches (and related refuelling infrastructure**) with 3 demos with the objective of improving the deployment of hydrogen in this segment.
- **Cars (and related refuelling infrastructure)** with 2 initiatives currently, demonstrating market readiness and best business cases for FC cars.

OPERATIONAL BUDGET: Following the calls launched from 2008 to 2023, the Clean Hydrogen JU supported 78 projects relevant for this pillar with a total Clean Hydrogen JU contribution of EUR 540.5 million and a contribution from partners of EUR 608.3 million. The distribution of funding among the research areas considered in this panel is shown in Figure 28.

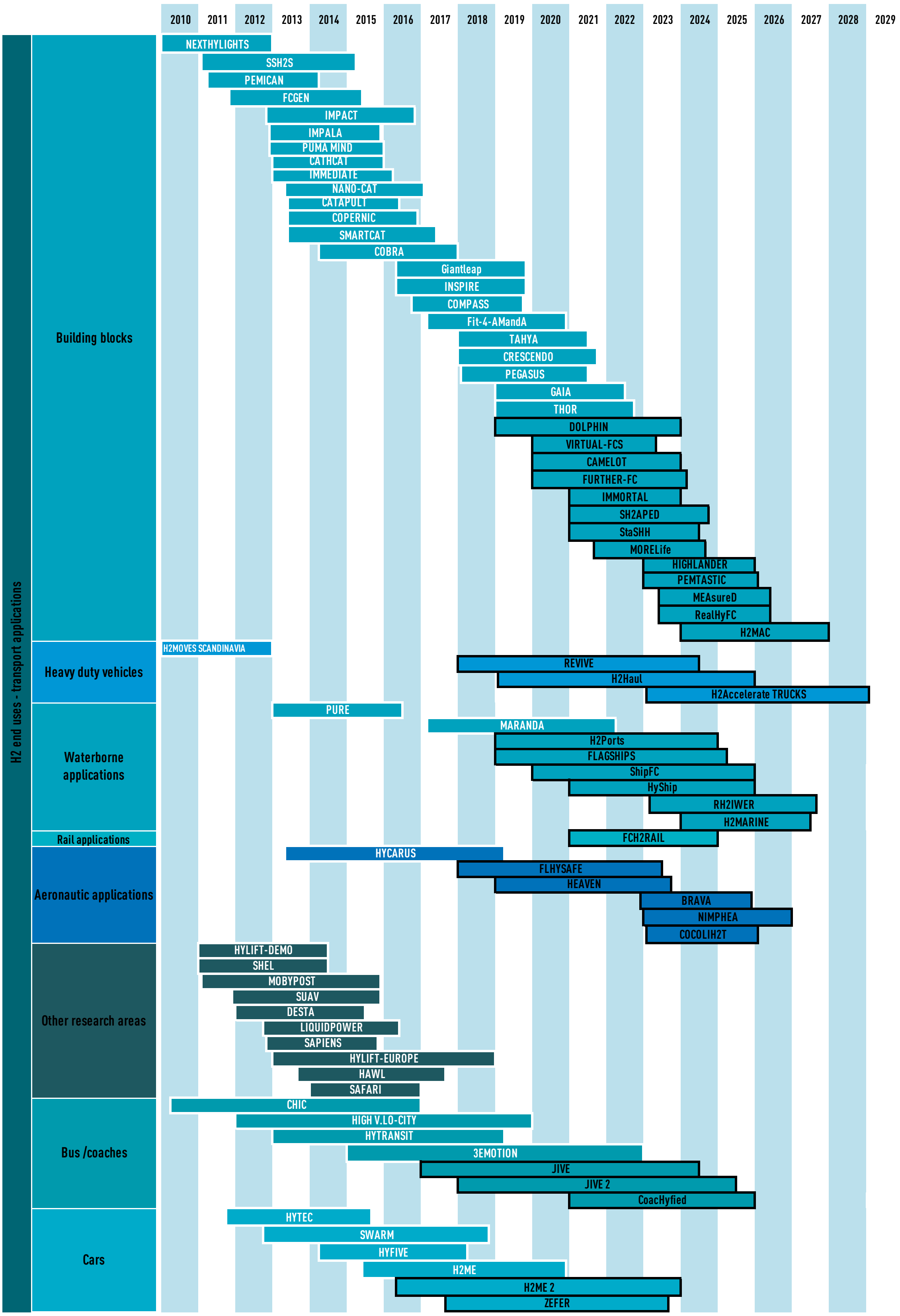
Figure 32: Funding for pillar 3 projects from 2008 to date



Source: Clean Hydrogen JU.

PROJECTS IN BRIEF: Figure 28 shows the pillar 3 projects, grouped by research area.

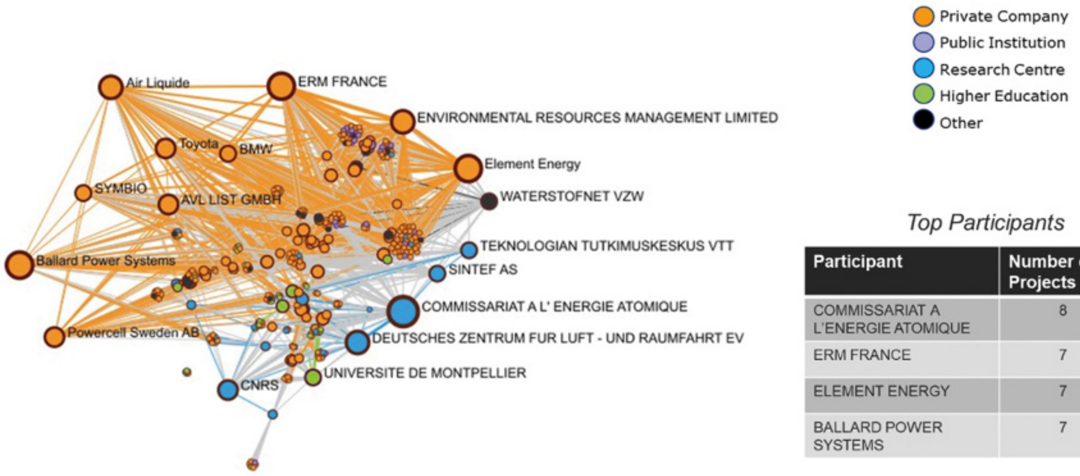
Figure 33: Project timelines for pillar 3 – H2 end-uses – transport



Source: Clean Hydrogen JU.

Figure 34 is a TIM plot showing the connections between partners present in the 33 projects reviewed within this year's Programme Review under Pillar 3. The size of the node (circle) represents the number of projects a partner is involved in, whilst the thickness of the lines linking the nodes represents the number of projects two partners have in common. The colour is based on the type of organisation as provided in CORDIS. The participants to the projects grouped under Pillar 3 often have strong links to each other. Research institutes (CEA) along with engineering and consulting companies (ERM France, Element Energy, Ballard Power Systems) are the key participants in this Pillar (i.e. those present in the most projects).

Figure 34: TIM plot showing the participants in the 33 projects in pillar 3



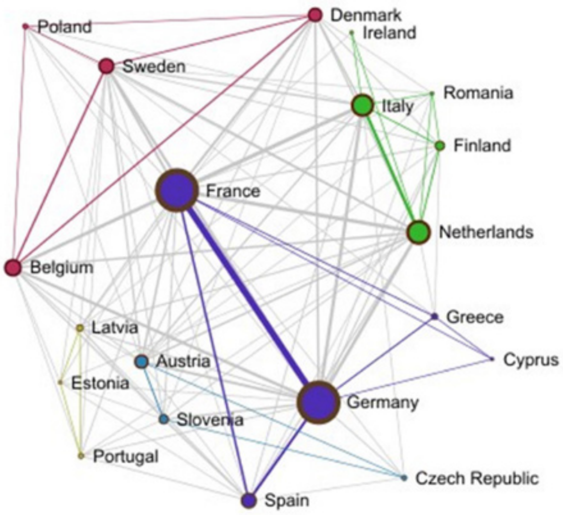
Top Participants

Participant	Number of Projects
COMMISSARIAT A L'ENERGIE ATOMIQUE	8
ERM FRANCE	7
ELEMENT ENERGY	7
BALLARD POWER SYSTEMS	7

Source: TIM, JRC, 2024.

Figure 35 shows the geographical distribution (EU Member States) of the participants active in this year's Pillar 3 project portfolio. In this case, the node represents the number of projects that have at least one partner from that country. The thickness of the links represents how many projects particular countries have in common. In terms of Member State participation, Germany, France, the Netherlands, Italy, Denmark and Belgium are involved in the most projects within Pillar 3. Of non-member states active in Pillar 3, the most active are United Kingdom, Switzerland and Norway who are represented in 19, 9 and 9 projects respectively. While Germany and France participate in the majority of projects (85 % and 82 % of the projects, respectively), there are Member States with very low participation (e.g. Romania, Cyprus, and Ireland participate in only 3 % of the projects). This discrepancy is due to the fact that the organizations participating in most projects are from Western European countries, which were pioneers in the field of hydrogen transport applications. However, it is worth noting that 18 out of the 27 EU Member States are participating in this pillar.

Figure 35: TIM plot showing EU Member State participation in Pillar 3 projects



Member State	Number of Projects
Germany	28
France	27
Netherlands	15
Italy	13
Denmark	13
Belgium	13

Source: TIM, JRC, 2024.

Projects on building blocks

Fuel cell system technologies

FURTHER-FC builds upon the PEMICAN[114] project, aiming to improve gas and proton transfer near catalytic structures and to investigate and validate performance limitations owing to coupling between electrochemical and transport issues in the cathode catalyst layer. It uses structural 3D characterisations and local operando diagnostics coupled with advanced modelling, from sub-µm to full thickness, addressing durability issues.

CAMELOT focused on improving understanding of transport limitations in FC electrodes. The project delivered next-generation PEMFC CCMs at industrially relevant scales, i.e. ~300 cm^2, and validated them in a 10-cell short stack exhibiting a peak power density of 1.04 W/cm^2, corresponding to a total catalyst loading of 0.17 mg Pt/W. Advanced CCM manufacturing techniques were developed to manufacture graded catalyst layers, which could be a promising strategy for homogenising current density and overcoming oxygen concentration gradients that develop between the inlet and outlet of a PEMFC. In addition, the optimisation of thin membranes at 8 µm provides a balance of high performance and minimised H_2 permeation. In this way, it was possible to obtain strong performance improvements in low-loading CCM designs, i.e. 0.1 mg Pt/cm^2 at the cathode, achieving power densities of up to 1.42 W/cm^2 in air at single-cell level.

Virtual-FCS aims to develop an open source (under MIT license) software-hardware toolkit for rapid design and optimisation of PEM FC/battery hybrid powertrains and systems for rail, maritime, bus and truck applications[115]. The project developed and validated the Virtual-FCS Modelica library containing plug-and-play models for building hybrid FC battery systems, including energy management strategies allowing for a more efficient and cost-effective way of designing reliable and high-performance hybrid systems[116]. The project also developed an XInTheLoop library and used it to integrate components from a physical hybrid system into the virtual system simulated in the software. The Virtual-FCS library has been verified/validated using user cases defined for maritime vessels, trucks and buses. The library has been disseminated throughout the FC community by training sessions, tutorials and a summer school.

114 PEMICAN PEM with innovative low-cost core for automotive application: https://cordis.europa.eu/project/id/256798/reporting

115 www.sintef.no/projectweb/virtual-fcs/newsandevents/virtual-fcs-opensource_platform

116 The Virtual-FCS library is available for download on GitHub (https://github.com/Virtual-FCS) and can be used together with the free Open Modelica modelling environment.

IMMORTAL developed new material concepts for PEMFC components (electrocatalysts, membranes) by building mitigation strategies for FC-operation-induced degradation to ensure both their activity and their stability are sustained. Future work (e.g. in HIGHLANDER) will use the IMMORTAL findings to develop MEAs allowing both the performance and durability targets of less than 10 % degradation to be achieved.

DOLPHIN aimed at validating an innovative route to production of lightweight and compact FC and stack architecture for lightweight and compact 100 kW FC stack designs. New manufacturing methods (printing, laser milling, additive manufacturing, etc.) have been developed to produce flow fields with thin dimensions on thin metallic and composite sheets. A test platform with six 100 cm^2 cells exhibits very high performance (close to the target of 2 W/cm^2) with the DOLPHIN cathode catalyst layer (CCL) and downsized rib-channels thanks to additive manufacturing, new membranes and new catalyst layer materials and formulation. A single cell with a 5 kW stack design combining the DOLPHIN CCM, flow-fields machined in the gas diffusion layer (GDL) and printing for the other parts has also shown very high performance (around 1.5 W/cm^2) and the highest values of kW/l and kW/kg.

MORELIFE, part of the AEVETO cluster[117], tries to ensure the highest impact for zero-emission road freight transport in Europe. It matches highly innovative material developments with advanced operating condition optimisation strategies in a direct feedback loop, using test data from thorough small-scale material evaluations, mechanistic modelling and measurement data from relevant application environments for HDVs.

STASHH aims to facilitate the design and manufacture of PEMFC systems for heavy-duty applications (trucks and ships). Subject to a revision once testing is complete at the end of the project, the development of standardised heavy-duty FC modules comprises three parts: definition of size, interfaces and the application programming interface (API) (input/output communication) being the public deliverables. For an impactful adoption of the three documents for FC module standards, submission to global standardisation bodies (SAE, IEC and ISO) is being considered.

RealHyFC will investigate efficiency and lifetime issues of PEMFCs in heavy-duty environments, local degradation and mechanical properties through developments in bipolar plates and balance of stack. It aims to deliver a public open-design platform demonstrating high efficiency, lifetime improvements and durability-oriented operation in heavy-duty environments simulated for long-lasting operation, diagnostics and monitoring of stacks. This will bring in new solutions based on improved physical degradation models, allowing virtual sensor algorithms to optimise FC operation and hybridisation.

HIGHLANDER develops fluorine-free MEAs for HDVs with disruptive, novel components, targeting stack cost and size, durability and fuel efficiency and ensuring, in tandem, compatibility and lowest interface resistance thanks to the following features: ionomer and reinforcement, catalyst and catalyst support, catalyst layer composition and property gradient in tune with the bipolar plate flow-field geometry.

PEMTASTIC targets the development of a durable CCM using innovative materials tailored for heavy-duty operation at high temperatures (105 °C).

MEAsureD aims to provide advanced, cost-effective PEMs and stable electrodes for MEA at higher temperatures (> 160 °C) based on a new ion-pair technology to reduce PGM use.

Projects on on-board hydrogen storage

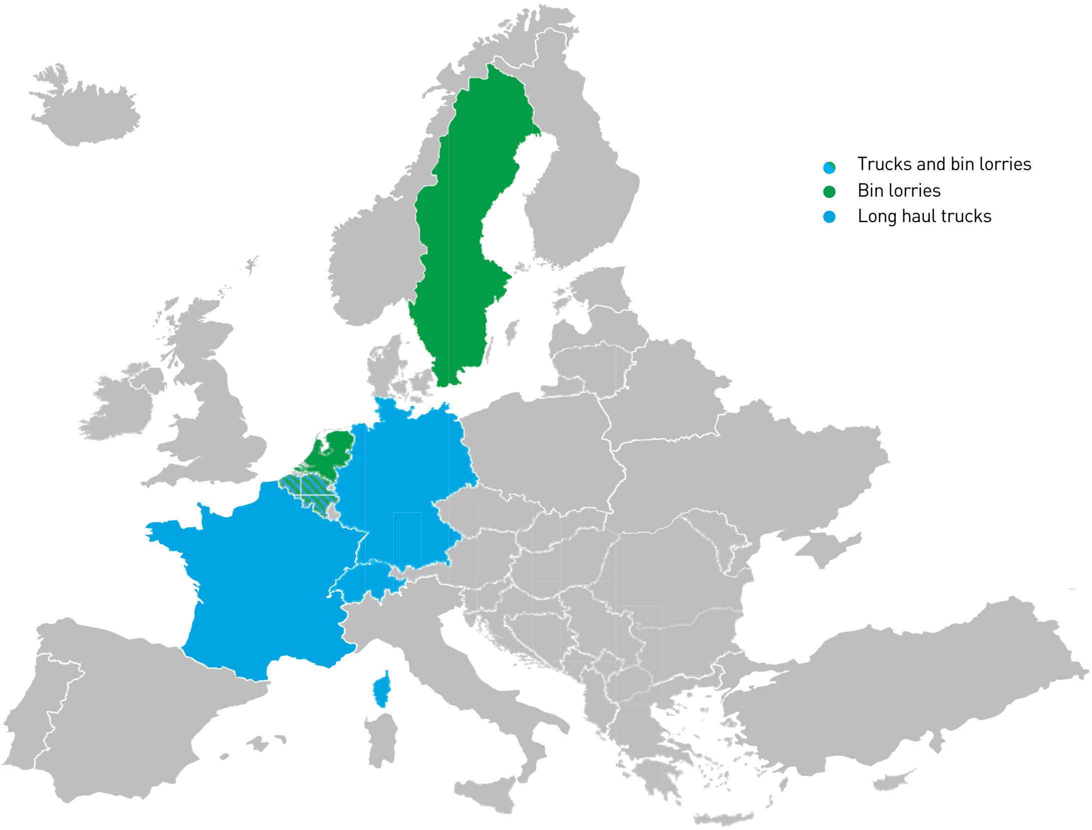
SH2APED plans to develop a conformable and cost-effective 700-bar compressed hydrogen storage system with increased efficiency and unique safety performance. It is also trialling the micro-leak-before-burst design in some vessels. The idea is that, in the event of a fire, the hydrogen will be released before the explosion of the tank and without needing a TPRD. SH2APED has achieved a volumetric efficiency of 43 % (stored hydrogen within the 1700x1400x150 mm size). As regards system costs, economic assessment for industrial mass manufacturing was in line with the expectations of the automotive industry.

117 https://zefes.eu/category/aeveto/

Heavy-duty vehicles

REVIVE started demonstration activities on heavy-duty trucks, and **H2HAUL** followed**.** These two projects will deploy 11 FC trucks and bin lorries at 13 sites in seven European countries, as shown in Figure 30.

Figure 36: Geographical distribution of HDVs from Clean Hydrogen JU projects



Source: Clean Hydrogen JU.

Six trucks are already in operation under **REVIVE**: two in Belgium, in Antwerp; and four in the Netherlands, in Breda, Arnhem and Son en Breugel. In 2023, those vehicles drove over 19 000 km and consumed 2.1 tonnes of hydrogen. Truck prices range from EUR 560 000-EUR 605 000. The HRSs in Gothenburg in Sweden and Groningen in the Netherlands started operation in 2021, while those in Breda and Antwerp opened in April and May 2022, respectively. The project will establish the basis and SoA reference for future heavy-duty bin lorries and will demonstrate the business case for hydrogen vehicle fleets for municipal services.

H2HAUL will deploy 16 trucks (including rigid and articulated vehicles up to 44 tonnes), which will be operated for at least 2 years in day-to-day service in four European countries. The FCETs will be integrated into the fleets of supermarkets like Carrefour in France, Colruyt in Belgium and a large retailer in Switzerland and used in logistics operations by DHL for BMW in Germany and by Air Liquide in France. The project aims at significantly increasing the technical maturity of the heavy-duty trucks, which are developed by two major European OEMs: Iveco FTP and VDL ETS. It will use FCs from three suppliers (Plastic Omnium, Bosch and PowerCell). The three funded HRSs have been commissioned and are operational, with the Swiss HRS being operational since 2021 and the French and Belgian HRSs since 2023. Operational data have been collected at the Swiss HRS.

H2ACCELERATE TRUCKS is a large-scale deployment project aimed at accelerating the uptake of hydrogen trucks in Europe. It started in February 2023. The project aims to deploy 150 trucks, manufactured by Daimler, Volvo and Iveco, and demonstrate them over 2 years. The trucks to be developed and deployed are 41-44 tonne articulated trucks with a range superior to 600 km, employing compressed H2 and liquid H2 fuels. H2ACCELERATE TRUCKS also aims to operate on a new network of high-throughput HRSs from Shell, Total and Everfuel. The trucks will be demonstrated in collaboration with more than 20 operators under a wide range of operating conditions and cover major Trans-European Transport Network corridors from northern to southern Europe.

Waterborne applications

SHIPFC will develop a 2 MW ammonia SOFC, as well as ship and land fuel systems for ammonia. It will integrate the full system on-board the Viking Energy platform support vessel. SHIPFC's vessel design will be the first to be powered with ammonia and use an SOFC at MW scale. SHIPFC is contributing to the development of green ammonia bunkering infrastructure in ports. The project is exploring the conditions for certification of green ammonia guarantees of origin. It has provided input into an LCA on alternative shipping fuels and the Viking Energy is used as a case study for ammonia-powered vessels. Another remarkable impact of SHIPFC is that the owners of the Viking Energy are committed to continuing its operation beyond the project end, gathering the operational data to analyse the performance requirements of ammonia-fuelled deep-sea vessels and assess their business case.

H2MARINE will design, build, test and validate two PEM stacks (from PowerCell in the EU and EH Group in Switzerland) generating 250-300 kW of electric power for marine applications.

HYSHIP will demonstrate a vessel powered with a 3 MW PEMFC system using liquid hydrogen. The vessel will transport goods from port to port along the west coast of Norway.

FLAGSHIPS will demonstrate two hydrogen FC fluvial vessels in commercial operation: one in Paris (France) and the other in Rotterdam (Netherlands). An interesting feature of the demo in Rotterdam is that the compressed hydrogen storage system is built inside a standard container that can be swapped. That simplifies the fuelling of the vessel, which will consist of exchanging the empty hydrogen storage container for a full one.

RH2IWER will demonstrate six different hydrogen FC-powered vessels (cargo, tanker and bulk) in inland waterway commercial operations[118]. The RH2IWER consortium includes three FC manufacturers, who will provide scalable FC systems approaching and exceeding 1 MW of power.

H2PORTS has as its objective the introduction of hydrogen and FC technologies as a zero-emission solution in maritime port logistics infrastructure. It will demonstrate and validate, under real operational conditions in the Port of Valencia, a hydrogen-powered reach stacker in a port container terminal, an FC yard tractor for container transport and roll-on/roll-off ship loading/unloading operations and a mobile hydrogen supply station. Both the reach stacker and the yard tractor are first-of-their-kind solutions, using FCs to provide 90 kW and 70 kW of power, respectively.

Rail applications

FCH2RAIL is developing a hybrid, bimodal drive system for trains powered by electrical supply either from the overhead line or by a hybrid pack consisting of FCs and batteries when no catenary line is available. The project is progressing well. In the course of 2023, the FC hybrid power pack was integrated into the demonstrator train (a refurbished electric commuter train)[119] and static tests were successfully carried out. Dynamic tests of the demonstrator train on a closed rail track took place in 2022. FCH2RAIL is currently testing the hydrogen train on public rail tracks[120] (Visit the Train – FCH2RAIL).

Aviation applications

FLHYSAFE draws on experience from HYCARUS for developing, validating (at TRL 5-6) and virtually demonstrating a cost-efficient, modular FC system (15-60 kW) to replace the most critical safety systems used as emergency

118 https://rh2iwer.eu/

119 The transformation of the train can be seen at https://youtu.be/bFBR6nhyEVI

120 https://www.caf.net/en/sala-prensa/nota-prensa-detalle.php?e=423

power units aboard commercial aeroplanes. The project successfully demonstrated short stack validation through H_2/O_2 tests, performed a critical design review of the LT module for the FC system (with theoretical A/C system specification) and conducted a first module test campaign, with the final demonstrator assembled and tested under environmental conditions.

HEAVEN aims to equip an existing 2-4-seater aircraft with an FC-based powertrain, thereby raising the aeronautic FC-based powertrain TRL from 3 to 6 and aiming to increase the autonomy of electric aircraft and the visibility and credibility of FC use in aircraft, as well as reducing the environmental impact of aviation at regional level. Project results are promising, showing an FC stack power mass density of 2.7 kW/kg[121], which meets the target of > 2.0 kW/kg, and an FC power volume density of 4.1 kW/litre, which meets the target of > 3.5 kW/litre.

NIMPHEA develops a new-generation HT MEA with a system size of 1.5 MW that is compatible with aircraft environments and requirements. It contributes to reaching high targets (1.25 W/cm² power density at 160 °C-200 °C operating temperatures and 3-5 mV/1 000 hours degradation) for the deployment of FCs in aviation.

BRAVA intends to develop breakthrough subsystem technologies (including catalysts, membranes, cooling systems, heat exchangers and air supply) that are lightweight and suitable for various working conditions and large amounts of power (multi-MW) and keep system safety and reliability levels at aeronautical standards.

COCOLIH2T is the first JU-funded project on liquid hydrogen storage onboard aircraft. The consortium will develop a LH2 tank of conformable shape, made of thermoplastic composite material and vacuum insulated. The concept will reduce the impact of the tank's weight and volume within an aircraft.

Buses and coaches

Together, **JIVE** and **JIVE 2** are deploying over 300 FC buses in 16 cities across Europe, the largest deployment in Europe to date[122]. The local fleets range in size from 5 to 50 FCEBs, typically 10 to 20. As of 2023, **JIVE** had ordered all 142 planned buses and 112 were in operation, while **JIVE 2** had ordered 122 buses out of the 159 planned, had 107 buses in operation and expected to have the entire fleet delivered by mid-2024. A total distance of more than 22 million km has been accumulated, of which 7.2 million km was in 2023 alone. In the last 7 years, over 1.7 million tonnes of hydrogen have been consumed, 20 % of which in 2024.

COACHYFIED is aiming to demonstrate coaches with FC powertrains for regional and long-distance passenger transport, focusing on the evolution of FC city bus drive systems in the coach sector.

Cars

The **H2ME** initiative (**H2ME** and **H2ME2** projects) is the largest European deployment of hydrogen mobility to date, aiming to deploy more than 1 100 vehicles in 10 countries and 50 HRSs from 10 suppliers in 6 countries. By the end of **H2ME2**, the **H2ME** initiative had deployed 1 492 vehicles and 49 HRSs in 9 countries. This is estimated to be equivalent to a third of the vehicles deployed in Europe in 2023. Vehicles in the projects have demonstrated driving range of up to 594 km, availability of close to 100 % and fuel efficiency of close to 1kg H_2 per 100 km. About 20 % of the individual HRSs are exceeding the availability target of 98 %.

H2ME2 has deployed 1 105 vehicles and put into operation 20 HRSs. All 20 HRSs had been commissioned and tested by the end of the project, including 8 additional HRSs commissioned in the final period of the project.

ZEFER demonstrated viable business cases for captive fleets of FCEVs (taxi, private hire and police services). The 180 FCEVs planned were deployed and put into operation (60 in Paris, 60 in London and 60 in Copenhagen). The cars in Paris were added to the already existing 74-FCEV HYPE taxi fleet[123], while in London 50 were used as private hire vehicles by Green Tomato and 10 were used as police vehicles. ZEFER upgraded three HRSs (Zaventem, Paris and London), and at the same time it made use of H2ME stations for refuelling operations.

121 https://hydrogen-portal.com/wp-content/uploads/2021/12/7.1.3-transport-aircrafts-fuel-cell-breakthroughs.pdf

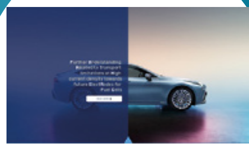
122 https://www.fuelcellbuses.eu/

123 https://hype.taxi/en/accueil-en/

PROJECT FACTSHEETS PILLAR 3

FURTHER-FC

FURTHER UNDERSTANDING RELATED TO TRANSPORT LIMITATIONS AT HIGH CURRENT DENSITY TOWARDS FUTURE ELECTRODES FOR FUEL CELLS



Project ID	875025
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	FCH-01-4-2019: Towards a better understanding of charge, mass and heat transports in new generation PEMFC MEA for automotive applications
Project total costs	EUR 2 735 031.25
FCH JU max. contribution	EUR 2 199 567.35
Project start - end	1.1.2020–31.8.2024
Coordinator	Commissariat à l'Énergie Atomique et aux Énergies Alternatives, France
Beneficiaries	Centre national de la recherche scientifique; Chemours France SAS; Deutsches Zentrum für Luft- und Raumfahrt EV; École nationale supérieure de chimie de Montpellier; Hochschule Esslingen; Imperial College of Science, Technology and Medicine; Institut national polytechnique de Toulouse; Paul Scherrer Institut; The Chemours Company FC, LLC; Toyota Motor Europe NV; Université de Montpellier; University of Calgary

https://further-fc.eu/

PROJECT AND GENERAL OBJECTIVES

Further-FC proposes platforms coupling experimental study and modelling to better understand the performance limitations of the cathode catalyst layers (CCLs) of low-Pt-loaded proton-exchange membrane fuel cells. Based on this, CCL improvements will be discussed and tested. Up-to-date references and some customised membrane electrode assemblies (with different ionomer-to-carbon ratios, thicknesses, etc.) have been produced, models of the CCLs are progressing based on their structural characterisation and the first effective properties have been derived.

NON-QUANTITATIVE OBJECTIVES

- Better understand the performance limitations of proton-exchange membrane fuel cells.
- Set up numerical and modelling tools to do so, focusing on the cathode catalyst layer.

PROGRESS AND MAIN ACHIEVEMENTS

- Progress has been made in the characterisation of the CCLs (through atomic force microscopy, Raman spectroscopy, 3D focused ion beam scanning electron microscopy, etc.).
- Progress has been made in the modelling of CCLs at different scales.
- The definition and validation of test protocols enables reliable comparison between the partners.
- Various customised membrane electrode assemblies have been manufactured, tested and characterised (through cyclic voltammetry, linear sweep voltammetry, electrochemical impedance spectroscopy, life cycle assessment, etc.).

FUTURE STEPS AND PLANS

- The finalisation of the characterisations of reference and customised membrane electrode assemblies is ongoing.
- The finalisation of the modelling of the CCLs at different scales is ongoing.
- The determination of the most performance-limiting mechanisms is ongoing.
- The upscaling of the models has started.
- The combined analysis of experiments and modelling to explain the role of different ionomers and/or catalyst supports on performance is ongoing.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?	SOA result achieved to date (by others)	Year for reported SOA result
MAWP (2014–2020)	Volumetric power density	kW/l	9.3		4.1	2017 (Auto-Stack CORE project)
	Weight power density	kW/kg	4		3.4	
	Surface power density	W/cm²	1.8		1.13	
	Cost	€/kW	20		36.8	
	Durability	hours	6 000		3 500	
	Total Pt load	mg/cm²	0.144		0.4	
		g/kW	0.08		0.35	
	Pt efficiency	A/mg	15		4.5	

CAMELOT

UNDERSTANDING CHARGE, MASS AND HEAT TRANSFER IN FUEL CELLS FOR TRANSPORT APPLICATIONS

Project ID	875155
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	FCH-01-4-2019: Towards a better understanding of charge, mass and heat transports in new generation PEMFC MEA for automotive applications
Project total costs	EUR 2 295 783.50
FCH JU max. contribution	EUR 2 295 783.50
Project start - end	1.1.2020–31.12.2023
Coordinator	SINTEF AS, Norway
Beneficiaries	Albert-Ludwigs-Universität Freiburg, Bayerische Motoren Werke AG, Fast Simulations UG, Fuel Cell Powertrain GmbH, Johnson Matthey Hydrogen Technologies Ltd, Johnson Matthey plc, PowerCell Sweden AB, Pretexo, Technische Universität Chemnitz

http://camelot-fuelcell.eu

PROJECT AND GENERAL OBJECTIVES

Camelot brought together highly experienced research institutes, universities, fuel cell membrane electrode assembly suppliers and original transport equipment manufacturers to improve their understanding of the limitations of fuel cell electrodes. This enabled the partners to provide guidance on the next generation of membrane electrode assemblies required to achieve the 2024 performance targets.

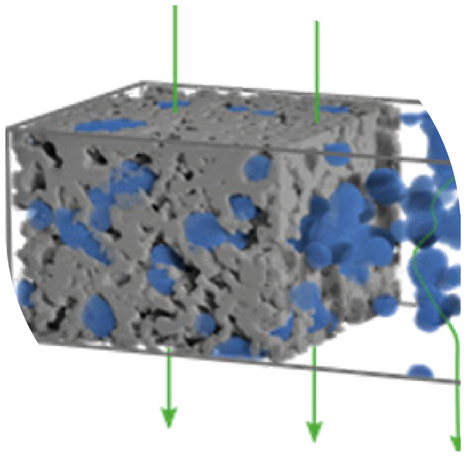
PROGRESS AND MAIN ACHIEVEMENTS

Next-generation proton-exchange membrane fuel cell catalyst-coated membranes were successfully manufactured at industrially relevant scales – that is, around 300 cm^2 – and validated in a 10-cell short stack exhibiting a peak power density of 1.04 W/cm^2, corresponding to a total catalyst load of 0.17 mgPt/W.

Advanced catalyst-coated membrane manufacturing techniques were developed to manufacture graded catalyst layers. It was shown that graded catalyst layers could be a promising strategy to homogenise current density and overcome oxygen concentration gradients that develop between the inlet and outlet of a proton-exchange membrane fuel cell.

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	Membrane thickness	μm	< 10	6	✓	N/A	2022
	Total MEA Pt load	mg/cm^2	0.08	0.18		0.2	2020
	Power density	W/cm^2	> 1.8	1.42 (single cell) and 1.04 (short stack)		1.8	2021
SRIA (2021–2027)	Power density	W/cm^2 at 0.65 V	1.2	0.64		N/A	N/A
	PGM loading	g/kW	< 0.30	0.173 (short stack)	✓	N/A	N/A

VIRTUAL-FCS

VIRTUAL & PHYSICAL PLATFORM FOR FUEL CELL SYSTEM DEVELOPMENT

VIRTUAL-FCS

Project ID	875087
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	FCH-01-3-2019: Cyber-physical platform for hybrid fuel cell systems
Project total costs	EUR 1 897 806.25
FCH JU max. contribution	EUR 1 897 806.25
Project start - end	1.1.2020–30.4.2023
Coordinator	SINTEF AS, Norway
Beneficiaries	Ballard Power Systems Europe AS, Banke ApS, Communauté d' universités et établissements Université Bourgogne–Franche–Comté, École nationale supérieure de mécanique et des microtechniques, SEAM AS, Solaris Bus & Coach Sp z.o.o., Université de Franche-Comté, Université de technologie de Belfort Montbéliard, Vivarail Ltd

https://www.sintef.no/projectweb/virtual-fcs/

PROJECT AND GENERAL OBJECTIVES

The overall objective of the Virtual-FCS project is to make the design process of hybrid fuel cell and battery systems easier, cheaper and quicker. Virtual-FCS will produce a toolkit combining software and hardware for designing and optimising hybrid systems of proton-exchange membrane fuel cells and batteries. The platform will be entirely open source, allowing everyone in both industry and research to benefit from and contribute to the future development of the framework. The software tools are being developed in close collaboration with end users and system integrators, securing widespread accessibility.

NON-QUANTITATIVE OBJECTIVES

- Virtual-FCS aims to significantly reduce development times for new fuel cell and battery hybrid systems. The advanced modelling, simulation and emulation tools developed in Virtual-FCS will enable end users with limited experience of fuel cell systems to design and implement new systems more quickly.
- The project aims to create a development platform for hybrid fuel cell systems with integration capabilities and corresponding simulation models. The real-time software platform combined with a full range of emulated components will enable end users to seamlessly integrate real, simulated and emulated components together in a mixed software–hardware system.
- It aims to create analytical tools and instrumentation to validate the different systems and energy management methodologies developed. Virtual-FCS will validate different energy management systems on the mixed software–hardware system. The characterisation of the systems will be carried out using the standard techniques to validate system performance.
- Virtual-FCS aims to create high-performance, real-time emulators of the dynamic behaviour of real components and subsystems. Virtual-FCS will develop new and improved balance-of-plant and stack models capable of accurate real-time emulation of components' dynamic performance, along with their degradation.
- The project aims to enable the establishment of an EU-based supply industry for hybrid fuel cell system simulation and the experimental tool environment (XIL platform) to boost the competitiveness of the EU fuel cell industry. The system simulation tools and methods for making and using the experimental platform will be available to the entire European industry free of charge to boost competitiveness.

PROGRESS AND MAIN ACHIEVEMENTS

- Virtual-FCS has demonstrated cyberphysical hardware integration.
- The project has demonstrated fuel cell electric vehicle simulations.
- The project has demonstrated real-time system emulation. It has demonstrated this capability by emulating a full stack system with an energy management strategy that can take real-time input from a physical sensor, use this feedback for real-time control of a standard fuel cell stack test bench and simulate various load cycles on the physical stack.
- The project has integrated components from the physical hybrid system into the system simulated in the software tools and those emulated on a controller.
- The project has arranged explanatory webinars and participated in conferences to demonstrate the feasibility of the Virtual-FCS library. An industrial workshop on 26 April 2023 was arranged.
- A simple fuel cell stack degradation model has been developed.
- Full validation of the fuel cell stack, battery and balance-of-plant models.

FUTURE STEPS AND PLANS

The project has finished.

Clean Hydrogen Partnership
Co-funded by the European Union

IMMORTAL

IMPROVED LIFETIME STACKS FOR HEAVY DUTY TRUCKS THROUGH ULTRA-DURABLE COMPONENTS

Project ID	101006641
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	FCH-01-2-2020: Durability-lifetime of stacks for heavy duty trucks
Project total costs	EUR 3 825 927.50
FCH JU max. contribution	EUR 3 825 927.50
Project start - end	1.1.2021–31.3.2024
Coordinator	Centre national de la recherche scientifique, France
Beneficiaries	Albert-Ludwigs-Universität Freiburg, AVL List GmbH, FPT Industrial SpA, FPT Motorenforschung AG, Johnson Matthey Hydrogen Technologies Ltd, Johnson Matthey plc, Pretexo, Robert Bosch GmbH, Université de Montpellier

https://immortal-fuelcell.eu

PROJECT AND GENERAL OBJECTIVES

Immortal aims to develop high-performance and high-durability membrane electrode assemblies (MEAs) and their components, specifically designed for use in heavy-duty trucks. The project intends to develop load profile tests specific to heavy-duty trucks, and apply these tests, and accelerated stress tests, to MEAs at both the subscale and the short-stack levels. The results of load profile testing will also be used to validate a novel lifetime prediction method, and the method used to predict the lifetime of project MEAs. The project will assess the results through a technoeconomic evaluation and facilitate heavy-duty fuel cell powertrain validation and provide system recommendations.

NON-QUANTITATIVE OBJECTIVES

Immortal contributes to activities in Mission Innovation's hydrogen innovation challenge through cooperation with the US Department of Energy's Million Mile Fuel Cell Truck consortium. Several workshops were held with the consortium, and with Japan's fuel cell platform. These included discussions on, inter alia, heavy-duty stressors, the second-generation Toyota Mirai and advanced characterisation techniques.

PROGRESS AND MAIN ACHIEVEMENTS

- Developed a nanofibre-reinforced membrane with exceptional durability in an MEA in accelerated stress testing at 90 °C, comprising 120 000 wet/dry cycles at open-circuit voltage corresponding to 2 200 hours in an accelerated stress test, without rupture.
- Developed MEAs comprising project materials that reached the 2024 strategic research and innovation agenda target for heavy-duty vehicles of 1.2 W/cm^2 at 0.65 V, and came within 5 % of the annual work programme target of 1.2 W/cm^2 at 0.675 V (for generation 2 MEAs), giving a Pt load of 0.32 gPt/kW.
- Developed a regression model for fuel cell degradation forecasting with an emphasis on the prediction confidence interval (uncertainty).
- Developed a method for creating accelerated durability tests for fuel cells, based on Markov chains..
- Established a lifetime prediction method and validated it using 1 500 hours of load profile testing.
- Obtained a predicted power loss of 10 % after 30 000 hours (for baseline MEAs), which corresponds to the annual work programme target.
- Identified the principal contributor to power loss during load profile testing as the loss of electrochemically active surface area from the cathode catalyst.
- Developed a modal load profile test from actual truck mission profiles.
- Achieved more than 7 500 hours of load profile testing on short stacks without catastrophic failure.

FUTURE STEPS AND PLANS

Immortal finished in March 2024 and the final activities were:

- finish the stack test;
- complete post-mortem analytics of MEAs from the last stack load profile test;
- provide heavy-duty fuel cell powertrain validation and system recommendations;
- complete a techno-economic evaluation.

Future plans including carrying forward the learning and most prospective materials from Immortal to future heavy-duty MEA development projects, in particular 'High performing ultra-durable membrane electrode assemblies for trucks' (Highlander).

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
SRIA (2021–2027) and AWP 2020	Cell voltage at 1.77 A/cm^2	V	675	0.642 (within 5 % of project/AWP target)		675	2021
	Durability	hours	30	10 % power loss after 30 000 hours		8 500	2020
Project's own objectives	Catalyst surface area and mass activity	cm^2/gPt and A/mgPt	Exceeding reference Pt and with better retention after accelerated degradation cycles than reference Pt/C	Two catalyst designs achieved this objective	✓	N/A	N/A
	Membrane durability in MEA AST cycles	cycles	50 000	110 000		N/A	N/A
AWP 2020	Cell voltage at 1.77 A/cm^2	V	675	661		675	2021

Clean Hydrogen Partnership
Co-funded by the European Union

DOLPHIN

DISRUPTIVE PEMFC STACK WITH NOVEL MATERIALS, PROCESSES, ARCHITECTURE AND OPTIMISED INTERFACES

Project ID	826204
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	FCH-01-6-2018: Game changer fuel cell stack for automotive applications
Project total costs	EUR 2 962 681.25
FCH JU max. contribution	EUR 2 962 681.25
Project start - end	1.1.2019–31.12.2023
Coordinator	Commissariat à l'Énergie Atomique et aux Énergies Alternatives, France
Beneficiaries	Chemours Belgium, Chemours France SAS, Chemours International Operations SARL, DMG MORI Additive GmbH, Faurecia systèmes d'échappement SAS, Hexcel Composites GmbH & Co. KG, Hexcel Composites Ltd, Hexcel Reinforcements SAS, Symbio, Symbio France, University of Manchester, Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg

http://www.dolphin-fc.eu/

PROJECT AND GENERAL OBJECTIVES

The overall aim of the project was to validate disruptive technologies for 100 kW lightweight and compact fuel cell stack designs, achieving outstanding (specific and volume) power density while simultaneously ensuring enhanced durability (under automotive application conditions) compared with state-of-the-art (SOA) stacks and compatibility with large-scale/mass production of full-power stacks. The validation of Dolphin technologies was supported by the design and fabrication of an automotive stack of 5 kW, representative of 100 kW power stacks.

NON-QUANTITATIVE OBJECTIVES

Evaluate the interest and limitations of different material and manufacturing technologies for proton-exchange membrane fuel cell stacks.

PROGRESS AND MAIN ACHIEVEMENTS

Increase in performance up to around 2W/cm², validated on a 100 cm² single cell, thanks to downsized rib/channel dimensions, a new membrane, new catalyst layer materials and formulation and alternative operating conditions (those of the GAIA project).

Identification of interest and limitations of various components of and manufacturing processes for proton-exchange membrane fuel cell stacks.

Design of potentially even more efficient flow fields and catalyst layer manufacturing processes.

The two best solutions have been defined to manufacture two stacks (5 kW). Manufacturing, assembly and testing of the 5 kW stacks based on the two technologies selected, to evaluate the key performance indicators (kW/l, kW/kg, W/cm², €/kW, µV/h).

In parallel, assessment of the benefit of adding a graphene coating to the membrane.

Definition and testing of an additional set of operating conditions to facilitate a trade-off between high stack efficiency (high pressure, Sto and relative humidity, as in the GAIA project) and high system efficiency (as used in Dolphin).

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 2018	Stack cost	€/kW	20	Evaluation is in progress and will be included in the final RP 4 documents		36.8	2017
	Durability	hours	6 000	Evaluation is in progress and will be included in the final RP 4 documents		3 500	2017
	Weight-specific power density	kW/kg	4	Projection based on TP 1 / TP 2 tests (to be checked at the stack level): 5–7 kW/kg		3.4	2017
	Volume-specific power density	kW/l	5	Evaluation will be included in the final RP 4 documents		4.1	2017
	Surface power density	W/cm²	2	2 (Dolphin components and GAIA operating conditions), validated on 100 cm² single cell		1.3 (AutoStack-Industry project) and 1.8 (GAIA project)	2017

MORELIFE

MATERIAL, OPERATING STRATEGY AND RELIABILITY OPTIMISATION FOR LIFETIME IMPROVEMENTS IN HEAVY DUTY TRUCKS

Project ID	101007170
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	FCH-01-2-2020: Durability-lifetime of stacks for heavy duty trucks
Project total costs	EUR 3 499 913.75
FCH JU max. contribution	EUR 3 499 913.75
Project start - end	1.9.2021–31.8.2024
Coordinator	AVL List GmbH, Austria
Beneficiaries	EKPO Fuel Cell Technologies GmbH; Mebius, Raziskovalno Razvojna Dejavnost, Zastopanje In Trgovina d.o.o.; Nedstack Fuel Cell Technology BV; Technische Universität München; Technische Universiteit Eindhoven; Univerza v Ljubljani

https://morelife-info.eu/

PROJECT AND GENERAL OBJECTIVES

The MORELife project addresses the need for highly efficient material utilisation, maximised durability and the optimised matching of operational conditions for proton-exchange membrane fuel cells in heavy-duty applications. Its objectives are to:

- perform accelerated stress tests for the shortened test duration for lifetime verification;
- make improvements at the material and operational strategy levels;
- create advanced degradation models;
- determine the optimal operating conditions and validate them based on the improved materials;
- achieve a predicted lifetime for fuel cells of 30 000 hours.

PROGRESS AND MAIN ACHIEVEMENTS

- Accelerated stress test and accelerated durability test protocols and aftertreatment systems for state-of-the-art and advanced catalyst material have been created.
- A third generation of novel catalyst material has been developed with promising first results of rotating disc electrode investigations.
- Post-mortem analyses on aged SOA material have been performed in order to improve mechanistic degradation models created in this project.

FUTURE STEPS AND PLANS

If proven sufficient, the third-generation catalyst will be integrated in a 5- to 10-cell short stack for validation in order to prove its durability and performance.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives and SRIA (2021–2027)	Power density per cell	W/cm² at 0.675 V / cell	1.2	
	PGM loading	g/kW	0	

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STASHH

STANDARD-SIZED HEAVY-DUTY HYDROGEN

Project ID	101005934
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	FCH-01-4-2020: Standard sized FC module for heavy duty applications
Project total costs	EUR 14 303 172.80
FCH JU max. contribution	EUR 7 500 000.00
Project start - end	1.1.2021–31.12.2024
Coordinator	SINTEF AS, Norway
Beneficiaries	Aktiebolaget Volvo Penta, Alstom Transport SA, AVL List GmbH, Ballard Power Systems Europe AS, Centro per gli Studi di Tecnica Navale SpA, Commissariat à l'Énergie Atomique et aux Énergies Alternatives, Damen Global Support BV, Damen Research Development & Innovation BV, FCP Fuel Cell Powertrain GmbH, FEV Europe GmbH, FEV Software and Testing Solutions GmbH, Freudenberg FST GmbH, Freudenberg Fuel Cell e-Power Systems GmbH, Future Proof Shipping BV, Hydrogenics GmbH, Hyster-Yale Italia SpA, Hyundai Motor Europe Technical Center GmbH, Intelligent Energy Ltd, Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek, Nedstack Fuel Cell Technology BV, Plastic Omnium New Energies Wels GmbH, Proton Motor Fuel Cell GmbH, Scheepswerf Damen Gorinchem BV, Solaris Bus & Coach Sp z.o.o., Symbio, Toyota Motor Europe NV, VDL Enabling Transport Solutions BV, VDL Energy Systems, VDL Special Vehicles BV, Volvo Construction Equipment AB, Volvo Technology AB, WaterstofNet VZW

https://stashh.eu

PROJECT AND GENERAL OBJECTIVES

Stashh's objectives are to agree on a standard for fuel cell modules across the heavy-duty sector (trucks, buses, ships, generators, trains, etc.), to build prototypes in accordance with this standard and to test them in accordance with agreed-upon methods. The project has produced three documents for standards, covering sizes, interfaces and communication; most fuel cell module suppliers have provided their prototypes, and some have already undergone testing.

NON-QUANTITATIVE OBJECTIVES

- The project aims to disseminate the standard. It has established contact with the Society of Automotive Engineers and the International Organization for Standardization.
- Stashh plans to update the standard in 2024, based on experience.

PROGRESS AND MAIN ACHIEVEMENTS

- A standard definition has been agreed.
- Stashh has created a comprehensive overview of regulations, codes and standards.
- All fuel cell modules have been designed, and two of the eight have been tested in accordance with the project's protocols.
- A truck prototype has been deployed at VDL.
- A best practices manual for original equipment manufacturers has been created.

FUTURE STEPS AND PLANS

- The final FCM testing campaigns will be conducted in 2024.
- The system will be demonstrated in the field.
- X-in-the-loop testing software will be created, and standard and designs will be finalised.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objectives	Number of sizes	pcs	3	3	✓
	Number of FC module partners	pcs	7	7	
	FC module power rating	kW	30–100	30–125	

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REALHYFC

RELIABLE DURABLE HIGH POWER HYDROGEN FUELED PEM FUEL CELL STACK

Project ID	101111904
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	HORIZON-JTI-CLEANH2-2022-03-01: Development and optimisation of reliable and versatile PEMFC stacks for high power range applications
Project total costs	EUR 3 487 157.50
FCH JU max. contribution	EUR 3 487 156.00
Project start - end	1.6.2023–31.5.2026
Coordinator	Commissariat a l'Énergie Atomique et aux Énergies Alternatives, France
Beneficiaries	AVL List GmbH, Deutsches Zentrum für Luft- und Raumfahrt EV, Dynergie, IRD Fuel Cells AS, PowerCell Sweden AB, United Motion Ideas, Univerza v Ljubljani, Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Wurttemberg

https://cordis.europa.eu/project/id/101111904

PROJECT AND GENERAL OBJECTIVES

The project's targeted key improvements are: (i) a new stable stack design, taking advantage of the two consolidated technologies with carbon and metal bipolar plates (from stationary and light-duty applications, respectively), coupled with improved balance of stacks, to hinder irreversible degradation of components; and (ii) optimised operational monitoring options precluding avoidable performance losses. SRIA solutions proposed will produce expected KPIs in terms of efficiency, performance and durability assessed in both representative conditions and scale.

In line with the Clean Hydrogen JU SRIA, RealHyFC will deliver evidence-based insights and models characterising the escalation of reversible and non-reversible losses attributed to critical characteristics of the heavy-duty use case:

- enhanced physical degradation of the core components (leading to irreversible losses), with significant risk of actual bipolar plate corrosion due to longer and harsher usage than in light-duty vehicles and stationary applications, respectively;
- increased local issues due to more significant heterogeneities associated with the large surface area needed to achieve a high power and coupled to driving cycles;
- more challenging control of operating conditions at the stack–system interface within acceptable boundaries for preventing faults and sustaining ultra-low degradation rates.

NON-QUANTITATIVE OBJECTIVES

- Identify performance and durability issues for heavy-duty transport applications;
- Develop model-based new diagnostic and monitoring tools with the aim of optimising hybridisation and operating strategies;
- Improve two key complementary items of the stack itself – use the best-suited bipolar plates to reduce corrosion risk, and optimise mechanical assembly to overcome heterogeneity issues to further enhance stack durability;
- Demonstrate performance and durability improvements in representative conditions at the stack scale;
- Ensure the exploitation of results and the increase of awareness of H2 for heavy-duty applications

PROGRESS AND MAIN ACHIEVEMENTS

- Manufacturing has starting using MEA components defined by the consortium.
- Relevant protocols and operating conditions for testing and modeling were considered so as to comply with the durability and control requirements.
- Degradation mechanisms related to core components and operating conditions have been modelled .
- The development of open-design carbon bipolar plates started.

FUTURE STEPS AND PLANS

- Delivery of MEAs and stacks, and assembly of reference stacks.
- Performance, sensitivity and durability testing based on selected protocols and definition of fuel cell diagnosis algorithms
- Modelling of stack performance and simulation of durability
- Manufacture of first open-design carbon bipolar plates.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?	SOA result achieved to date (by others)	Year for reported SOA result
AWP 2022	Degradation for a projected durability of 20 000 hours with fewer than 10 % losses	%	10		N/A	2024
	Power density	W/cm² at 0.675 V at BOL	1		1	2024

HIGHLANDER

HIGH PERFORMING ULTRA-DURABLE MEMBRANE ELECTRODE ASSEMBLIES FOR TRUCKSMARITIME SECTOR

Project ID	101101346
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	HORIZON-JTI-CLEANH2-2022-03-02: Innovative and optimised MEA components towards next generation of improved PEMFC stacks for heavy duty vehicles
Project total costs	EUR 3 331 247.50
FCH JU max. contribution	EUR 3 331 247.50
Project start - end	1.1.2023–31.12.2025
Coordinator	Centre national de la recherche scientifique, France
Beneficiaries	Elmarco s.r.o., Forschungszentrum Jülich GmbH, Johnson Matthey Hydrogen Technologies Ltd, Johnson Matthey plc, Pretexo, Rhodia Laboratoire du Futur, Rhodia Operations, Robert Bosch GmbH, Solvay Specialty Polymers Italy SpA, Speciality Operations France, Technische Universität Berlin, Université de Montpellier

https://highlander-fuelcell.eu/

PROJECT AND GENERAL OBJECTIVES

The objective of Highlander is to develop membrane electrode assemblies (MEAs) for heavy-duty vehicles (HDVs) with disruptive, novel components, targeting stack cost and size, durability and fuel efficiency. The project will involve the design, fabrication and validation of the HDV MEAs at the cell and short-stack levels using accelerated stress test and load profile test protocols for heavy-duty vehicles. Material-screening efforts will be supported by the development and use of improved predictive degradation models bridging scales from the reaction site level to the cell level. Model parameterisation will be implemented using experimental characterisation data at the materials, component and cell levels. Highlander aims to bring about a significant reduction in stack cost and fuel consumption through improving catalyst-coated membrane performance and developing a new, lower-cost single-layer gas diffusion. It also aims to achieve the 1.2 W/cm² at 0.65 V performance target at 0.3 gPt/kW or less, meeting a lifetime target of 20 000 h. Sustainability considerations include benchmarking fluorine-free membranes for HDV MEA application and the reuse of platinum in the context of a circular economy.

PROGRESS AND MAIN ACHIEVEMENTS

- Implementation of liquid and gas phase characterisation tools online involving the electrochemical cycling of project catalysts to identify degradation products and determine correlations between them and electrochemical potential, and implementation of measurement methods for convective transport, electrical bulk conductivity and contact resistance of gas diffusion layers.
- Development of a series of novel ordered intermetallic catalysts on novel heteroatom-doped carbon and on reference carbon for the project that display a higher retained mass activity and electrochemical surface area than the reference catalyst for the project.
- Progress in the development of two series of novel sulfonated hydrocarbon ionomers for fluorine-free membranes and their benchmarking against perfluorosulfonic acid membranes.
- Advancement in the elaboration of low-cost gas diffusion layers with the development of a low-cost anode gas diffusion layer (GDL) giving identical performance to commercial GDLs.
- Formulation of a hierarchical degradation modelling framework and its implementation as a software code, available in the open access modelling platform (GitLab).

FUTURE STEPS AND PLANS

- Upscaling of selected catalysts for catalyst layer development and single-cell characterisation.
- Preparation of initial nanofibre-reinforced membrane and its delivery for catalyst coating and testing of initial project MEAs against project performance and durability targets.
- Pursuit of development of a novel low-cost cathode GDL, catalyst and ionomer, along with support materials and other membrane components.

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
SRIA (2021–2027) and AWP 2022	Durability of FC stack	hours	20	500 hours to end of test on single cell		30 000 (predicted based on 1 500 hours of actual load profile testing)	2023
	Power density	W/cm² at 0.65 V	1.2	N/A		1.2	2022
	PGM loading	g/kW	< 0.3	MEAs prepared with 0.42 mgPt/cm²		0.34	2023

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PEMTASTIC

ROBUST PEMFC MEA DERIVED FROM MODEL-BASED UNDERSTANDING OF DURABILITY LIMITATIONS FOR HEAVY DUTY APPLICATIONS

PEMTASTIC

Project ID	101101433
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	HORIZON-JTI-CLEANH2-2022-03-02: Innovative and optimised MEA components towards next generation of improved PEMFC stacks for heavy duty vehicles
Project total costs	EUR 2 748 608.75
FCH JU max. contribution	EUR 2 748 608.50
Project start - end	1. 2. 2023 - 31. 1. 2026
Coordinator	Deutsches Zentrum für Luft- und Raumfahrt EV, Germany
Beneficiaries	Chemours Belgium; Chemours France SAS; Commissariat à l'Énergie Atomique et aux Énergies Alternatives; Heraeus Deutschland GmbH & Co. KG; Imerys Graphite & Carbon Belgium; Imerys Graphite & Carbon Switzerland SA; IRD Fuel Cells AS; Symbio France; The Chemours Company FC, LLC; Zürcher Hochschule für Angewandte Wissenschaften

https://pemtastic-project.eu/

PROJECT AND GENERAL OBJECTIVES

The research and development project Pemtastic aims to tackle the key technical challenges to increasing the durability of membrane electrode assemblies (MEAs) for heavy-duty applications. These challenges are approached using a combination of model-based design and the development of a durable catalyst-coated membrane (CCM) using innovative materials tailored for heavy-duty operation at a high temperature (105 °C). The quantitative targets correspond to a durability of 20 000 hours, maintaining a state-of-the-art (SOA) power density of 1.2 W/cm^2 at 0.65 V at a Pt load of 0.30 g/kW.

NON-QUANTITATIVE OBJECTIVES

- Define fuel cell operation protocols and cycling tests for heavy-duty applications and propose an operational strategy for high fuel efficiency.
- Parameterise degradation models to predict MEA lifetime and identify specific improvements in the CCM and its components.
- Develop a robust catalyst (Pt/C) support deposition process for oxygen reduction reaction catalysts.
- Develop membranes and ionomers that operate at high temperatures.
- Create catalyst layers and CCM with increased durability and state-of-the-art performance tailored for heavy-duty operation.

PROGRESS AND MAIN ACHIEVEMENTS

- The partners developed operation protocols for testing materials, single cells, and short stacks. These protocols are available as a public report and have been shared with other Clean H2 projects related to MEA or stack development.
- Specific in situ and ex situ tests were discussed among modellers and experimentalists.
- In the context of the modelling task, performance models were set up to extend to degradation based on the results for the Gen1 MEA.
- Significant effort was dedicated to implementing and debugging testing conditions for single cells into partner test benches to achieve sufficient reproducibility. Initial testing was conducted using a commercial MEA from IRD Fuel Cells, and durability tests were conducted using Pemtastic heavy-duty load cycling and characterisation protocols. The reproducibility of durability tests at different facilities will be assessed.
- The Gen1 MEA was designed using materials from Imerys, Heraeus, and Chemours. A Gen2 MEA will be designed in the second year, considering inputs from degradation models.
- The project was presented at three fairs, contributed to nine workshops or conferences, and was advertised on social media.

FUTURE STEPS AND PLANS

Next steps for the second year of project implementation are:

- Demonstrate reproducible durability among partners;
- Carry out specific accelerated stress tests for the parametrisation of degradation models;
- Identify the most important degradation mechanisms using the first-generation project MEA;
- Provide input for MEA improvement from degradation models;
- Identify specific improvements to be implemented in second-generation materials and components;
- start analysing second-generation MEAs and improve/extend degradation models.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?	SOA result achieved to date (by others)
SRIA (2021–2027)	Power density	W/cm^2 at 0.65 V	1.2		1.00
	PGM loading	g/kW	0.3		0.4
	Durability	hours	20		15
Project's own objectives	Operational temperature	°C	95–105 at low RH		80–85 °C

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MEASURED

ADVANCED MEAS ENSURING HIGH EFFICIENCY HDV

Project ID	101101420
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	HORIZON-JTI-CLEANH2-2022-03-02: Innovative and optimised MEA components towards next generation of improved PEMFC stacks for heavy duty vehicles
Project total costs	EUR 2 989 060.00
FCH JU max. contribution	EUR 2 989 060.00
Project start - end	1.6.2023–31.5.2026
Coordinator	Advanced Energy Technologies AE Ereunas & Anaptyxis Ylikon & Proiontonananeosimon Pigon Energeias & Synafon Symvouleftikon y Piresion, Greece
Beneficiaries	AVL List GmbH, AVL-AST Napredne Simulacijske Tehnologije d.o.o., Honeywell International s.r.o., Technische Universitaet Graz, Universitat Politècnica de València, University of Stuttgart, Univerza v Ljubljani

https://measured-horizon.eu/

PROJECT AND GENERAL OBJECTIVES

At Measured, we strive to improve the efficiency and lifespan of high-temperature membrane electrode assemblies (MEAs) for heavy-duty vehicles through a combination of experiments and simulations. Our focus is on developing and optimising MEA components to enhance the overall performance of fuel cells. Specifically, we aim to use high-temperature proton-exchange membranes (HT-PEMs), which we believe is the best scientific direction for the heavy-duty vehicle (HDV) industry. We plan to achieve key performance indicators beyond the current state of the art (SOA) by developing the ion-pair concept. Our consortium, led by Advent, an MEA manufacturer, and comprising fuel cell technology experts, is dedicated to linking HT-PEMs with HDV applications. We will optimise technical aspects to deliver an advanced MEA with high-end potential for the HDV sector based on cost and environmental analyses.

Our research will focus on improving MEA durability and performance through experimental and theoretical approaches. Our ultimate objective is to demonstrate a cost-effective MEA that operates at high temperatures (> 160 °C) with high performance.

The project's objectives are as follows.

- Develop an MEA for a HT-PEM suitable for an HDV that operates at a temperature > 160 °C with minimum phosphoric acid uptake and a stable porous microstructure ionomer / new type of platinum catalyst.
- Integrate MEAs in a short stack. Project stack performance based on short-stack measurements. Evaluate MEAs' performance according to the project's key performance indicators. The environmental assessment of the fuel-cell-manufacturing procedure is focused on cost reduction and the recycling of waste products.
- Integrate fuel cell stacks in HDVs in real conditions. Identify balance-of-plant components based on HT-PEM needs. Analyse the use of fuel cell technology for other applications (aviation, maritime, rail).
- Develop design and monitoring modelling (flow field, degradation) simulation tools.
- Carry out testing-, harmonisation- and standardisation-related activities.

NON-QUANTITATIVE OBJECTIVES

- Cultivate expertise in digital modelling techniques, enabling the team to develop sophisticated simulations that enhance understanding and inform design decisions.
- Conduct vehicle-level simulations, fostering a deep understanding of system-wide implications and interdependencies.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives and SRIA (2021–2027)	Cost of FC stack	€/kW	< 75	
	PGM loading for low TRL	g/kW	< 0.30	
	Stack durability	hours	20 000	
	Power density	W/cm^2 at 0.65 V	1.2	

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SH_2APED

STORAGE OF HYDROGEN: ALTERNATIVE PRESSURE ENCLOSURE DEVELOPMENT

Project ID	101007182
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	FCH-01-1-2020: Development of hydrogen tanks for electric vehicle architectures
Project total costs	EUR 1 993 550.00
FCH JU max. contribution	EUR 1 993 550.00
Project start - end	1.1.2021–30.9.2024
Coordinator	Plastic Omnium Advanced Innovation and Research, Belgium
Beneficiaries	Bundesanstalt für Materialforschung und -prüfung, Misal SRL, OMB Saleri SpA, Optimum CPV, University of Ulster

https://sh2aped.eu/

PROJECT AND GENERAL OBJECTIVES

The goal of the SH_2APED project is to develop and test at technology readiness level 4 a conformable and cost-effective 70 MPa hydrogen storage system with increased efficiency and exceptional safety performance.

NON-QUANTITATIVE OBJECTIVES

Regarding certification procedures, the project aims to contribute to the revision of regulations.

PROGRESS AND MAIN ACHIEVEMENTS

- The first design of the assembly has been finalised (several types are available). The vessel design has also been completed and made available:
  - vessel design;
  - manifold and thermal pressure release device design;
  - vessel prototypes.
- System testing of the model's reaction to fire is in progress.

FUTURE STEPS AND PLANS

Frame design is ongoing.

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	Low-cost process for liner	€	1 million	1 million		3 million	2021
	Burst pressure (R134)	MPa	> 157.5	170	✓	157	2022
	Hydraulic pressure cycle test, 87.5 MPa at 20 °C	number of cycles	22 000	> 22 000		Not published	Not published
	H_2 storage volume of estimated design space	%	> 45	43		41	2021
	Cost of tank system	€/kgH_2	400	> 580		N/A	2022
	Permeation	$Ncm^3/l/h$ at 55 °C	-	Not yet available		N/A	N/A

REVIVE

REFUSE VEHICLE INNOVATION AND VALIDATION IN EUROPE

Project ID	779589
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	FCH-01-7-2017: Validation of fuel cell trucks for the collect of urban wastes
Project total costs	EUR 9 760 023.65
FCH JU max. contribution	EUR 4 993 851.00
Project start - end	1.1.2018–31.12.2024
Coordinator	Tractebel Engineering (Tractebel), Belgium
Beneficiaries	Azienda Servizi Municipalizzati di Merano SpA, Commissariat à l'Énergie Atomique et aux Énergies Alternatives, Element Energy Ltd, ENGIE Impact Belgium, Environmental Resources Management Ltd, ERM France, E-Trucks Europe, Gemeente Amsterdam, Gemeente Breda, Gemeente Groningen, Gemeente Noordenveld, Plastic Omnium New Energies Fribourg SA, PowerCell Sweden AB, Prezero Nederland Holding BV, Proton Motor Fuel Cell GmbH, Renova Aktiebolag, Saver NV, Servizi Energia Ambiente Bolzano SpA, Stad Antwerpen, Symbio, Tractebel Belgium, Waterstofnet VZW

https://h2revive.eu/about-revive/

PROJECT AND GENERAL OBJECTIVES

Revive will significantly advance the state of development of fuel cell bin lorries by integrating fuel cell powertrains into 11 vehicles and deploying them at eight sites across Europe. The project will deliver substantial technical progress by integrating fuel cell systems from four major suppliers and by developing effective hardware and control strategies to meet highly demanding refuse truck duty cycles. Today, all trucks are in operation.

NON-QUANTITATIVE OBJECTIVES

- The project aims to involve EU fuel cell suppliers. Currently, two EU fuel cell suppliers are involved in the project: Proton Motor and PowerCell Sweden. In addition, two trucks are equipped with Hydrogenics fuel cell systems.
- The project aims to demonstrate a route to the high utilisation of hydrogen refuelling stations to support the roll-out of H_2 mobility for light-duty vehicles. Even with limited running hours, the three trucks deployed in the project have already consumed 4.2 t of H_2 during the project.

PROGRESS AND MAIN ACHIEVEMENTS

- The first Proton Motor fuel cell system has been delivered and successfully integrated.
- The first Revive trucks have been deployed.
- A new electric driveline has been developed, tested and deployed.
- All trucks have been constructed and have all the certifications required to be deployed.

FUTURE STEPS AND PLANS

- Increase dissemination activities. To catch up following the delays experienced in 2020, a plan for dissemination will be developed.
- Decrease teething issues.
- Carry out an in-depth performance analysis of truck deployment and focus on completing the remaining deliverables.

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 2017	Driving distance between FC failures	km	3 500	6 210		N/A	N/A
	FC power	kW	> 40	45	✓	90	N/A
	Tank-to-wheel efficiency	%	50	55		N/A	N/A
	Lifetime	hours	25 000	N/A		> 25 000	2020
	FCs deployed in the project	number	15	6		6	N/A
	Availability	%	90	77		N/A	N/A

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H_2HAUL

HYDROGEN FUEL CELL TRUCKS FOR HEAVY-DUTY, ZERO EMISSION LOGISTICS

Project ID	826236
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	FCH-01-1-2018: Large scale demonstration of H_2 fuelled HD trucks with high capacity hydrogen refueling stations (HRS)
Project total costs	EUR 28 110 126.80
FCH JU max. contribution	EUR 12 000 000.00
Project start - end	1.2.2019–31.12.2025
Coordinator	Environmental Resources Management Ltd, United Kingdom
Beneficiaries	Air Liquide Advanced Business, Air Liquide Advanced Technologies SA, Air Liquide France Industrie, Bayerische Motoren Werke AG, DATS 24, Element Energy Ltd, ElringKlinger AG, EOLY, Environmental Resources Management France, Etablissementen Franz Colruyt NV, FPT Industrial SpA, FPT Motorenforschung AG, H2 Energy AG, Hydrogen Europe, Hydrogenics GmbH, IRU Projects ASBL, Iveco SpA, Plastic Omnium New Energies Wels GmbH, PowerCell Sweden AB, Robert Bosch GmbH, Sphera Solutions GmbH, TotalEnergies Marketing Deutschland GmbH, Union internationale des transports routiers, VDL Enabling Transport Solutions BV, VDL Special Vehicles BV, WaterstofNet VZW

https://www.h2haul.eu/

PROJECT AND GENERAL OBJECTIVES

H_2Haul brings together two major original equipment manufacturers for European trucks (Iveco and VDL) and the fuel cell stack/system suppliers (Plastic Omnium, Bosch and PowerCell) to develop and demonstrate fleets of heavy-duty trucks in day-to-day commercial operations in four sites across four countries. The overall objective of H_2Haul is to prove that hydrogen trucks can be a practical zero-emission and zero-carbon solution for much of Europe's trucking needs and, in doing so, pave the way for the commercialisation of fuel cell trucks in Europe. The project is currently at the end of the planning and pre-deployment phase, and all trucks and hydrogen refuelling stations (HRSs) funded by the project are expected to be deployed in the next 12 months.

NON-QUANTITATIVE OBJECTIVES

- H_2Haul aims to develop long-haul heavy-duty (26 t and 44 t) fuel cell trucks that meet customers' requirements in a range of operating environments. The trucks' design and specifications are being finalised in alignment with specific customer requirements and mission profiles. The objectives are expected to be met.
- The project aims to homologate three fuel cell truck types to certify that they are safe to use on Europe's roads. Original truck equipment manufacturers are working closely with hydrogen safety experts and the relevant certification bodies to secure all necessary safety approvals for using the trucks on public roads in Europe.
- The project aims to develop the business case for the further roll-out of heavy-duty fuel cell trucks. H_2Haul will provide a valuable database of real-world performance information and insights into the next steps required for the commercialisation of this sector. The business case is to be developed based on fuel cell truck designs that meet customers' needs. The operation of fuel cell trucks and the subsequent data collection will highlight the costs of the technology. Analyses will be carried out to highlight the economics of the more ambitious deployment of many tens of vehicles or more.
- H_2Haul aims to prepare the European market for the further roll-out of fuel cell trucks through (i) developing innovative commercial models and (ii) disseminating information from the project to a wide audience of relevant stakeholders. H_2Haul's dissemination activities will share key findings with relevant audiences to prepare the market for the wider roll-out of fuel cell trucks on a commercial basis. Communication activities in the first and second years of the project stimulated significant interest from relevant audiences.

PROGRESS AND MAIN ACHIEVEMENTS

- The fuel cell truck technical specifications were finalised. Data were gathered on the technical specifications of the fuel cell trucks and HRSs.
- All three project-funded HRSs were deployed.
- The second observer group meeting took place.

FUTURE STEPS AND PLANS

- H_2Haul will deploy the VDL and Iveco trucks. The VDL trucks will be delivered to Colruyt in July 2024 to start commercial operation. The Iveco beta trucks are currently being assembled with fuel cells from Bosch and will serve as prototypes for the 12 gamma trucks that will be delivered to end users in France, Germany and Switzerland between May and June 2024.
- The H_2Haul team will continue their high-profile dissemination and lobbying work through attending and delivering presentations at key conferences and events. Other stakeholder engagement activities will also continue. The results will be disseminated extensively.

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PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives and MAWP addendum (2018–2020)	Operational period of trucks	months	With the period of operation including the ramp-up phase: ≥ 24	
	Distance travelled by trucks	km	≥ 30 000 per truck per year, on average per site	
	Availability of trucks	%	> 90 % for the fleet after an initial ramp-up phase lasting a maximum of 6 months	
	Specific fuel consumption of trucks	kg / 100 km	Rigid truck at 30–50 % load, for inner city delivery (< 25 km/h on average): < 7.5; tractor with semi-trailer at 30–50 % load, for long-haul delivery (> 65 km/h on average): < 8.5	
	Availability of stations (by end of project)	%	99	
	MDBF	km	> 2 500	
	WTW CO_2 emissions	$kgCO_2/km$	$kgCO_2/km$ (per vehicle type; average across fleet)	
	Speed of hydrogen dispensing	kg/min	> 2.5	
	Cost of hydrogen dispensed to HRS	€/kg	7.5	
	Amount of hydrogen dispensed to trucks deployed in the project	kg/year	> 2 500	

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H_2ACCELERATE TRUCKS

LARGE SCALE DEPLOYMENT PROJECT TO ACCELERATE THE UPTAKE OF HYDROGEN TRUCKS IN EUROPE

Project ID	101101446
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	HORIZON-JTI-CLEANH2-2022-03-03: Large scale demonstration of European H_2 heavy duty vehicle along the TEN-T corridors
Project total costs	EUR 110 946 587.25
FCH JU max. contribution	EUR 29 991 488.50
Project start - end	1.2.2023–31.1.2029
Coordinator	SINTEF AS, Norway
Beneficiaries	Daimler Truck AG, Element Energy Ltd, ERM France, Everfuel AS, Federazione Italiana Autotrasportatori Professionali, IVECO SpA, Linde GmbH, OMV Downstream GmbH, Shell Nederland Verkoopmaatschappij BV, Teknologian Tutkimuskeskus VTT Oy, TotalEnergies Gas Mobility BV, Union internationale des transports routiers, Uniunea Naţională a Transportatorilor Rutieri din România, Volvo Lastvagnar AB, Volvo Technology AB, Wirtschaftskammer Österreich

https://h2accelerate.eu/trucks/

PROJECT AND GENERAL OBJECTIVES

The overall goal of the project is to support the transition of fuel cell trucks from technically proven but high-cost demonstrators to a viable commercial choice for operators across Europe.

To achieve the above goal, the general objectives are to:

- deploy 150 fuel cell trucks weighing between 41 t and 44 t in nine European countries by the end of 2029;
- operate the trucks on a hydrogen refuelling station network designed for zero-emission truck deployment, operated by Everfuel, Shell and TotalEnergies;
- analyse technical, environmental, economic and attitudinal data to determine the viability of H_2 fuel cell trucks as a solution to decarbonise road freight;
- raise awareness of the benefits of using green H_2 for trucking in Europe through a wide range of targeted communication activities.

PROGRESS AND MAIN ACHIEVEMENTS

The project is still in its initial phase. Multiple activities have commenced, including:

- the adaptation of manufacturing facilities to accommodate fuel cell truck production;
- preparations for homologation and type approval;
- original equipment manufacturers' initial preparations for fleet launch.

Main achievements and results so far include:

- dialogue with heavy-duty truck end users and hydrogen refuelling station network operators;
- the development of and agreement on protocols for data monitoring and analysis;
- the assessment of health and safety issues and submission of an appropriate safety plan;
- the submission of original equipment manufacturers' annual progress reports.

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PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Gross weight of HD trucks deployed	t	41–44	
	Vehicle range under heavy load	km	> 600 km for compressed H_2 and > 1 000 km for liquid H_2	
	Distance driven per truck (during deployment phase)	km/year	≥ 60 000	
	Annual CO_2 emission savings	t/year	Confirmation (by LCA) of a saving across the fleet of 21 000 t/year	
	End-user groups to allow detailed discussion of hydrogen-powered trucks with users not involved in the project	number of events/ meetings	3	
	Dataset covering the performance of 150 trucks	number of reports	Shareable reports (including regular updates) of technical and economic performance of and end users' attitudes to hydrogen trucks in day-to-day operation	
	Cost of trucks	€	< 450 000	
	Central and eastern European potential truck operators in end-user groups	number	> 20	
	Green hydrogen demand created	t/year	2 100	
	Data monitoring and analyses of trucks' performance	% of deployed trucks	20 (corresponding to 30 trucks of the full fleet of 150 trucks)	
	Demand for electrolyser capacity created	MW	26 (assuming a 50 % load factor to achieve green supply)	
	FC module CAPEX	€/kW	605	
	FC stack durability	hours	20 000	
	Dedicated truck road tour visits in EU Member States	number of Member States	5	
	Distance driven across the entire fleet	km/year	15 million	
	Presentations at events and conferences	number per year	5	✓
SRIA (2021–2027)	Vehicle availability	%	> 95	
AWP 2022	Operational period monitored per truck	months	24	
	Visible social media and web presence	number	2	✓
	H_2/FC powered HD trucks deployed	number	150	

SHIPFC

PILOTING MULTI MW AMMONIA SHIP FUEL CELLS

Project ID	875156
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	FCH-01-2-2019: Scaling up and demonstration of a multi-MW fuel cell system for shipping
Project total costs	EUR 13 179 056.25
FCH JU max. contribution	EUR 9 975 477.50
Project start - end	1.1.2020–31.12.2025
Coordinator	Maritime CleanTech, Norway
Beneficiaries	Alma Clean Power AS, Capital-Executive Ship Management Corp, Clara Venture Labs AS, Eidesvik Shipping AS, Equinor Energy AS, Fraunhofer Gesellschaft zur Förderung der Angewandten Forschung EV, National Centre for Scientific Research 'Demokritos', North Sea Shipping AS, Persee, Star Bulk Shipmanagement Co. (Cyprus) Ltd, Sustainable Energy AS, University of Strathclyde, Wärtsilä Gas Solutions Norway AS, Wartsila Norway AS, Yara Clean Ammonia Norge AS, Yara International ASA

https://shipfc.eu/

PROJECT AND GENERAL OBJECTIVES

ShipFC's main mission is to prove and demonstrate the case for large-scale zero-emission shipping through developing, piloting and replicating a modular 2 MW fuel cell technology using ammonia as fuel. The project will also prove the case for large-scale, zero-emission fuel infrastructure through a realistic business model. Currently, the fuel cells are being scaled up and going through laboratory testing.

NON-QUANTITATIVE OBJECTIVES

- ShipFC aims to integrate ammonia fuel cell and fuel systems into ship power systems. The integrated ship design is now used in the ongoing approval process for the vessel. Initial discussions with key players from the industry are complete and follow-up actions have been identified. The vessel design and approval process will contribute to updating knowledge in the industry, as this is the first vessel with MW-scale ammonia-powered solid oxide fuel cells (SOFCs) on board.
- For the replicators, the fourth-generation design for the container ship is now established.
- Concept evaluations of bulk carriers are ongoing
- The project aims to demonstrate the wider use of the system and the scale-up of the system by 20 MW. The first-generation design for the 5 000 twenty-foot equivalent unit container ship has been established. As the detailed designs of all systems for Viking Energy progress, the container ship design will be modified several times.
- As part of the work, the project will also perform a safety assessment of the ammonia fuel gas system and of the SOFC system.

PROGRESS AND MAIN ACHIEVEMENTS

- The project has signed an agreement for the delivery of green ammonia fuel for the duration of the project (not analysed or published).
- Detailed designs for the fuel system have been developed.
- The vessel design has been developed for the ammonia fuel cell installation, including the fuel gas system.
- The approval process for ammonia-powered vessels is ongoing with the class and the flag state.
- A purchase order for two MW SOFC stacks has been placed.

FUTURE STEPS AND PLANS

- ShipFC will scale up and test the SOFC.
- The project partner Alma is currently performing laboratory-scale testing of SOFCs, and is preparing for the first large-scale SOFC test (100 kW), to be commenced in 2024.
- The project partner Sustainable Energy has set up the test infrastructure required to facilitate the 100 kW test, including the necessary ammonia tank and fuel gas system.
- The consortium will follow up and monitor the delivery of stacks for the 2 MW system. A further plan is to refine the design for the 2 MW system based on results from the 100 kW tests.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objectives	GHG reduction by use of ammonia fuel	%	70	N/A	
	Power of ammonia SOFC system	MW	2	0.006	
	SOFC operational experience	hours	3 000	N/A	

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H_2MARINE

HYDROGEN PEM FUEL CELL STACK FOR MARINE APPLICATIONS

Project ID	101137965
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	HORIZON-JTI-CLEANH2-2023-03-02: Development of a large fuel cell stack for maritime applications
Project total costs	EUR 7 499 171.50
FCH JU max. contribution	EUR 7 499 171.50
Project start - end	11.1.2024–30.6.2027
Coordinator	Ethniko Kentro Erevnas kai Technologikis Anaptyxis, Greece
Beneficiaries	Albert-Ludwigs-Universität Freiburg, Beyond Gravity Schweiz AG, Cleos Idiotiki Kefalaiouchiki Etaireia, Cluster Viooikonomias kai Perivallontos Dytikis Makedonias, École polytechnique fédérale de Lausanne, EH Group Engineering SA, Greenerity GmbH, PowerCell Sweden AB, Reinz-Dichtungs GmbH, Teknologian Tutkimuskeskus VTT Oy, ThyssenKrupp Marine Systems GmbH, Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg

https://h2marineproject.eu

PROJECT AND GENERAL OBJECTIVES

The overarching objective of the H_2Marine project is to design, build, test and validate two proton-exchange membrane stacks generating 250–300 kW electrical power designed for marine applications. The H_2Marine project takes a top-down approach, building on a proof of concept of two proton-exchange stacks that are being developed in the EU and Switzerland. The H_2Marine project will:

- identify the requirements for the tests and conditions as well as load curves that the fuel cell stacks will have to be tested against, using the combined knowledge of a major ship-building company (ThyssenKrupp Marine Systems) and a shipowner (Cleos);
- enable both the PowerCell and the EH Group stack manufacturers to benefit from a great consortium surrounding their development, testing and upscaling with unique testing facilities (Beyond Gravity, Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg, Greenerity, University of Freiburg), industrial partners such as DANA, the upscaling of stacks by Ethniko Kentro Erevnas kai Technologikis Anaptyxis and École polytechnique fédérale de Lausanne, and novel diagnostics development by VTT, which will allow them to enhance the state of the art of proton-exchange membrane fuel cell stacks, and advance and scale up the system to reach ambitious targets set in the call that will be disseminated by CLUBE (a member of numerous fuel cell and hydrogen projects);
- test the proposed solutions in a relevant environment/ecosystem, designed to fully represent the actual implementation conditions;
- design the stack modules in an optimum manner for upscaling to 10 MW train systems;
- test several diagnostics for the integrity of the stack and overall system and for the prognosis of the health status of critical components;
- assess the technology and economic feasibility of the solution, in order to determine its valuable end use, which will allow the partners to research the potential market(s) and identify the best opportunities.

NON-QUANTITATIVE OBJECTIVES

- Test the proposed solutions in a relevant environment/ecosystem, representing actual marine conditions.
- Design the stack modules in an optimum manner for upscaling to 10 MW.
- Test several diagnostics for the integrity of the stack and overall system and for the prognosis of the health status of critical components.
- Assess the technology, and the economic and environmental feasibility of the solution, in order to determine its valuable end use.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Module rating	kW	250	
	Hours of testing for each FC	hours	2 000	
	PEMFC system CAPEX	€/kW	< 1 500	
	FC power rating	MW	10	
	Maritime FCS lifetime	hours	> 40 000	

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H_2MAC

HYDROGEN FUEL CELL ELECTRIC NON-ROAD MOBILE MACHINERY FOR MINING AND CONSTRUCTION: AN INNOVATIVE, EFFICIENT, SCALABLE, SILENT AND MODULAR POWER-TRAIN CONCEPT

Project ID	101137786
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	HORIZON-JTI-CLEANH2-2023-03-01: Real environment demonstration of non-road mobile machinery (NRMM)
Project total costs	EUR 6 278 930.00
FCH JU max. contribution	EUR 4 990 769.76
Project start - end	1.1.2024–31.12.2027
Coordinator	Instituto Tecnológico de Aragón, Spain
Beneficiaries	Asociación Española de Fabricantes Exportadores de Maquinaria para Construcción, Obras Publicas y Mineria; Ballard Power Systems Europe AS; Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón; Hidromek Maquinaria de Construccion España SL; Hidromek – Hydrolik Ve Mekanik Makina Imalat Sanayi Ve Ticaret AS; Mann + Hummel GmbH; Talleres ZB SA; Tampereen Korkeakoulusaatio SR; Zamalbideservice2021 SL

https://h2mac.eu

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Noise reduction	dB	< 100	
	New technologies feasible and commercially viable	number/project	2	
	Emission reduction	CO_2eq/year	0	
	FC system efficiency (TCO reduction)	%	50	
SRIA (2021–2027)	Safety reporting	%	100	
	FC module CAPEX	€/W	< 800	
	FC module availability	%	80	
	FC stack durability	hours	16 000	
	Impact on standards at scope	number/project	1	

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FLAGSHIPS

CLEAN WATERBORNE TRANSPORT IN EUROPE

Project ID	826215
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	FCH-01-2-2018: Demonstration of fuel cell applications for midsize passenger ships or inland freight
Project total costs	EUR 6 766 811.83
FCH JU max. contribution	EUR 4 999 978.75
Project start - end	1.1.2019–31.3.2025
Coordinator	Teknologian tutkimuskeskus VTT Oy, Finland
Beneficiaries	ABB Oy, Ballard Power Systems Europe AS, Compagnie Fluviale De Transport, Future Proof Shipping BV, Kongsberg Maritime AS, LMG Marin AS, LMG Marin France, Maritime CleanTech, Norled AS, Persee, SEAM AS, Sogestion, Sogestran

https://flagships.eu/

PROJECT AND GENERAL OBJECTIVES

Two commercially operated hydrogen fuel cell vessels will be demonstrated, one in France (Paris) and one in the Netherlands (Rotterdam). The Paris demonstration vessel is a self-propelled barge operating as a goods transport vessel in the city centre; the Rotterdam demonstration vessel is a container vessel transporting goods between Rotterdam and Duisburg. The Paris demonstration vessel has been built and is en route to France, where hydrogen fuel cell systems will be installed. Work started on the Rotterdam demonstration vessel at the end of 2021, and the vessel was launched in February 2024.

NON-QUANTITATIVE OBJECTIVES

- The project aims to develop and demonstrate bunkering technologies based on swapping gaseous hydrogen fuel containers.
- Procedures for hydrogen bunkering by swapping hydrogen storage containers are being developed and will be demonstrated in 2024.

PROGRESS AND MAIN ACHIEVEMENTS

- The FCwave fuel cell module has been approved by the DNV.
- The *Zulu* (Paris demonstration vessel) was designed and built. The vessel is at the yard in Le Havre. ABB and Ballard Power Systems Europe systems are already there and installation work has started. The vessel has been granted a recommendation from the Central Commission for the Navigation of the Rhine.
- The *H_2 Barge II* demonstration vessel was launched and started operating in March 2024.

FUTURE STEPS AND PLANS

- The *Zulu 06* vessel will be launched in summer 2024.
- The commercial operation of both vessels will be demonstrated for 18 months.

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	Complete FC and H_2 system cost	€/kW	4 000	⚙	N/A	N/A
	FC systems demonstrated on board vessel in commercial operation	months	2 × 18	⚙	9	2023
	Develop necessary safety measures for H_2 and FC vessels to enable the approval of their class	-	Class approval gained	✓	Yes	2023
	PEMFC system availability	%	95	⚙	N/A	N/A
MAWP addendum (2018–2020)	PEMFC system lifetime	hours	25 000	⚙	N/A	N/A

RH_2IWER

RENEWABLE HYDROGEN FOR INLAND WATERWAY EMISSION REDUCTION

Project ID	101101358
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	HORIZON-JTI-CLEANH2-2022-03-05: Large scale demonstration of hydrogen fuel cell propelled inland waterway vessels
Project total costs	EUR 20 531 971.25
FCH JU max. contribution	EUR 14 998 541.38
Project start - end	1.3.2023–31.8.2027
Coordinator	Teknologian Tutkimuskeskus VTT Oy, Finland
Beneficiaries	Air Liquide BV, Ballard Power Systems Europe AS, Compagnie Fluviale de Transport, DFDS AS, Future Proof Shipping BV, H_2Boat SRL, Air Liquide SA, Air Liquide Belge, Nedstack Fuel Cell Technology BV, Sogestion, Stichting Projecten Binnenvaart, Theo Pouw BV, Università degli Studi di Genova, Verenigde Tankrederij BV

http://rh2iwer.eu/

PROJECT AND GENERAL OBJECTIVES

The main aim of RH_2IWER is to create a solid basis for the acceleration of vessels powered by hydrogen fuel cells in inland waterway shipping by demonstrating six commercially operated vessels. These vessels are of varying lengths and types: 86 m, 110 m and 135 m; and container, bulk and tanker vessels with installed power ranging from 0.6 MW to around 2 MW. The project will also work to standardise containerised fuel cell and hydrogen solutions. Through demonstration, standardisation work and multilevel analyses, combined with vigorous dissemination and communication measures, the RH_2IWER project will create a basis on which the shipping industry can significantly reduce its environmental footprint and remove emissions from its entire fleet in the future.

NON-QUANTITATIVE OBJECTIVES

- Demonstrate the use of inland waterway vessels powered by hydrogen fuel cells.
- Accelerate adoption by facilitating cooperation and exploiting synergies within the European maritime sector.
- Promote the acceptance of inland waterway vessels powered by hydrogen fuel cells as a viable zero-emission solution.
- Increase the impact of inland waterway transport on decarbonisation.

PROGRESS AND MAIN ACHIEVEMENTS

RH_2IWER partners have been working to develop the demonstration vessels' general design, as well as with the business cases. Partners have also started to work on standardising fuel cell and hydrogen storage containers in order to alleviate the risks for shipowners in the future when adopting these technologies.

FUTURE STEPS AND PLANS

Next in the project, the hydrogen and fuel cell systems on board the vessels will be designed in more detail and then the vessels will built/retrofitted and their use demonstrated.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	PEMFC system CAPEX	€/kW	1.35	
	H_2 and FC vessels demonstrated	number	6	
	Professionals trained	number	80	
	FC power rating	MW	2	
	Maritime FCH lifetime	hours	40	
	Safety, PNR and RCS workshops	number/year	1	
	Safety reporting	%	100	
	Projects with a proactive safety management process	%	100	
	Product design achieving type approval	number	2	

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H_2PORTS

IMPLEMENTING FUEL CELLS AND HYDROGEN TECHNOLOGIES IN PORTS

Project ID	826339
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	FCH-03-1-2018: Developing fuel cell applications for port/harbour ecosystems
Project total costs	EUR 4 117 197.50
FCH JU max. contribution	EUR 3 999 947.50
Project start - end	1.1.2019–31.12.2024
Coordinator	Fundación de la Comunidad Valenciana para la Investigación, Promoción y Estudios Comerciales de Valenciaport, Spain
Beneficiaries	Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile; Atena Scarl – Distretto Alta Tecnologia Energia Ambiente; Autoridad Portuaria de Valencia; Ballard Power Systems Europe AS; Cantieri Del Mediterraneo SpA; Centro Nacional de Experimentación de Tecnologías de Hidrógeno y Pilas de Combustible Consorcio; Enagas SA; Grimaldi Euromed SpA; Hyster-Yale Nederland BV; Mediterranean Shipping Company Terminal Valencia SA; Sociedad Española de Carburos Metálicos SA; Università degli Studi di Napoli Parthenope; Università degli Studi di Salerno; Valencia Terminal Europa SA

https://h2ports.eu/about/

PROJECT AND GENERAL OBJECTIVES

The H_2Ports project will demonstrate and validate two innovative solutions based on fuel cell technologies. A reach stacker and a terminal tractor will be tested on a daily basis during real operational activities at the Port of Valencia. The required hydrogen will be provided through a mobile hydrogen refuelling station (HRS) designed and built during the project. All three elements are currently in advanced stages of building, and the piloting period is planned to start in 2024.

NON-QUANTITATIVE OBJECTIVES

- The project aims to disseminate H_2 technologies to the port and maritime sector. This goal will be accomplished through the organisation of a stakeholder advisory group.
- H_2Ports will gather information on the use of H_2 in port environments.
- It will also gather information on the use of H_2 as fuel for vessels.

PROGRESS AND MAIN ACHIEVEMENTS

Both the reach stacker and the yard tractor have been commissioned, and their demonstration could start in the first half of 2024.

FUTURE STEPS AND PLANS

It is envisaged that the two applications (reach stacker and 4 × 4 terminal tractor) will undergo 2 years of piloting under normal operative conditions. The piloting period is expected to start in 2024.

PROJECT TARGETS

Target Source	Parameter	Unit	Target	Target Achieved?
Project's own objectives, MAWP addendum (2018–2020) and AWP 2018	Amount of H_2 dispensed	kg/day	60	
	MTBF	days	-	
	Tank-to-wheel efficiency	%	50	
	Hydrogen consumption	kg/h	RS: 3.33; YT: 2.34	
	Hydrogen storage cost	€/kg	650	
Project's own objectives	HRS daily capacity	kg/day	60	
	Reach stacker vehicle power	kW	90	
	Vehicle power	kW	70	
	Noise level	dBA	< 60	
	HRS MBTF	days	50	
	Availability	%	90	
	HRS availability	%	> 98	
	Specific maintenance cost	€/output	TBD	
	Hydrogen refuelling time	minutes	< 30	
	Vehicles over cost (target percentage over CNG and diesel port trucks)	%	100	
	Cost of fuel cell system	€/kW	3 500	
	Duration of the testing period	h–years	5 000–2	
	Total installed power of fuel cell system	kW	175–205 (225–285)	
	HRS-specific maintenance cost	€/kg	1	
	HRS CAPEX	€	575 000	

FCH$_2$RAIL

FUEL CELL HYBRID POWERPACK FOR RAIL APPLICATIONS

Project ID	101006633
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	FCH-01-7-2020: Extending the use cases for FC trains through innovative designs and streamlined administrative framework
Project total costs	EUR 13 378 484.93
FCH JU max. contribution	EUR 9 999 999.12
Project start - end	1.1.2021–31.12.2024
Coordinator	Deutsches Zentrum für Luft- und Raumfahrt EV, Germany
Beneficiaries	Administrador de Infraestructuras Ferroviarias, CAF Digital & Design Solutions SA, CAF Power & Automation SL, CAF Turnkey & Engineering SL, Centro de Ensayos y Analisis SL, Centro Nacional de Experimentación de Tecnologías de Hidrógeno y Pilas de Combustible Consorcio, Construcciones y Auxiliar de Ferrocarriles Investigacion y Desarrollo SL, Construcciones y Auxiliar de Ferrocarriles SA, Faiveley Transport Leipzig GmbH & Co. KG, Infraestruturas de Portugal SA, Renfe Operadora, Renfe Viajeros SA, Stemmann-Technik GmbH, Toyota Motor Europe NV

www.fch2rail.eu

PROJECT AND GENERAL OBJECTIVES

The project consortium is developing and testing a new train prototype. At the heart of the project is a hybrid, bimodal driving system that combines the advantages of an electrical power supply from an overhead line with a hybrid power pack consisting of fuel cells and batteries. This system enables more sustainable and energy-efficient rail transport. The project will show that this type of bimodal power pack is a competitive and environmentally friendly alternative to diesel power.

NON-QUANTITATIVE OBJECTIVES

An expert network with external stakeholders has been created to support the analysis of gaps in the normative framework. Work package 7 network meetings were held in 2023 and the gap analysis was shared with and commented on by the work package 7 network.

Exchanges and collaboration with other EU projects (standard-sized heavy-duty hydrogen (Stashh), Virtual & physical platform for fuel cell system development (Virtual-FCH), European hydrogen train the trainer programme for responders (Hyresponder), Europe's rail flagship project 4 – sustainable and green rail systems (Rail4Earth)) and national projects (H2goesrail, Use of hydrogen fuel cell drives in local transport in the district of Barnim, operated with 100 % renewable hydrogen (H2BAR)) have taken place.

PROGRESS AND MAIN ACHIEVEMENTS

- Fuel cell hybrid power pack (FCHPP) development and tests on a Centro Nacional del Hidrógeno test bench were successfully completed.
- The physical integration of two FCHPPs into the demonstration train was successfully completed.
- The first static test of a FCHPP in a train was conducted.
- The dynamic testing of the demonstration train on closed tracks was conducted.
- Technology readiness level 7 authorisation was obtained for the demonstration system for Spain.
- The functioning of the first H_2-powered train was demonstrated on the Spanish railway network.
- The train demonstration was finalised in Madrid and Galicia.
- Technology readiness level 7 authorisation was obtained for Portugal.
- More than 4 600 km were demonstrated in H_2 mode before the end of 2023.
- Train demonstration is ongoing on several lines in Spain.

FUTURE STEPS AND PLANS

- Demonstration of a bimodal train in Portugal.
- Receipt of theoretical track authorisation for Germany.

PROJECT TARGETS

Target source	Parameter	Target achieved?
Project's own objectives	System lifetime/durability	
	Hydrogen and electricity consumption	

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FLHYSAFE

FUEL CELL HYDROGEN SYSTEM FOR AIRCRAFT EMERGENCY OPERATION

Project ID	779576
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	FCH-01-1-2017: Development of fuel cell system technologies for achieving competitive solutions for aeronautical applications
Project total costs	EUR 7 296 552.51
FCH JU max. contribution	EUR 5 063 023.00
Project start - end	1.1.2018–30.6.2023
Coordinator	Safran Power Units, France
Beneficiaries	Arttic, Commissariat à l'Énergie Atomique et aux Énergies Alternatives, Deutsches Zentrum für Luft- und Raumfahrt EV, Instituto Nacional de Técnica Aeroespacial Esteban Terradas, Safran Aerotechnics, Universität Ulm

https://www.flhysafe.eu/

PROJECT AND GENERAL OBJECTIVES

In the shift towards more electric aircraft, fuel cell systems are considered one of the best options for efficient power generation.

The main objective of Flhysafe was to demonstrate that a cost-efficient modular fuel cell system can replace the most critical safety systems and can be used as an emergency power unit aboard a commercial aeroplane, providing enhanced safety functions. In addition, the project had the objective of virtually demonstrating that the system can be integrated, respecting both installation volumes and maintenance constraints, into current aircraft designs.

PROGRESS AND MAIN ACHIEVEMENTS

- The short stack was validated by H_2/O_2 tests.
- A critical design review of the low-temperature module for the fuel cell system was performed (and theoretical air conditioning system specifications were produced).
- A critical review of the design of major subsystems of the demonstration system was performed.
- The first module campaign test was performed
- The final demonstration system was assembled
- Operational and environmental tests of the Flhysafe demonstration system were carried out.
- The use of fuel cell technology in an emergency power unit was found to be very challenging.
- Regulations are not mature enough.
- As regulations have not yet been issued by authorities, there is still a chance that the architecture proposed in Flhysafe may need to be adapted in the future. Safran and the Spanish National Institute for Aerospace Technology are taking part in discussions through working group 80 of Eurocae.
- Fuel cell system components are not yet ready for aeronautical use and need more specific studies and development.
- The technology is not mature enough for aeronautical needs.
- The applications of low-temperature proton exchange membranes for ground-based automotive applications are well understood, but the membranes cannot be applied to aeronautical systems without further research and design efforts.
- Ram air turbines have been established by major players as offering a reliable technology for aircraft. Other options, such as fuel cells, could be considered only for new hydrogen-powered aircraft.
- However, Flhysafe has contributed to a better understanding of fuel cell technology in various domains.
  - The French industrial supply chain is increasing its maturity in manufacturing some fuel cell stack parts (metallic bipolar plates and seals).
  - One patent is in progress (co-ownership between Safran and Sealicone).
  - Understanding of O_2 use in aeronautics is improving.
  - Safety analysis is improving (through the collaboration of Deutsches Zentrum für Luft- und Raumfahrt and Safran).
  - Smart solutions are needed to tackle integration challenges, and the CEA has developed an interesting option with its direct current–direct current system.

FUTURE STEPS AND PLANS

The project has finished.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objectives	Weight of EPU	kg	150	220	⚙
	System power density	W/kg	100	78	⚙
	Nominal continuous electrical power	kW	18.1	18.1	✓

HEAVEN

HIGH POWER DENSITY FC SYSTEM FOR AERIAL PASSENGER VEHICLE FUELLED BY LIQUID HYDROGEN

Project ID	826247
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	FCH-01-4-2018: Fuel cell systems for the propulsion of aerial passenger vehicle
Project total costs	EUR 6 903 128.81
FCH JU max. contribution	EUR 3 995 305.00
Project start - end	1.1.2019–30.9.2023
Coordinator	H_2FLY GmbH, Germany
Beneficiaries	Air Liquide Advanced Technologies SA, Deutsches Zentrum für Luft- und Raumfahrt EV, EKPO Fuel Cell Technologies GmbH, Fundación Ayesa, Air Liquide SA, Pipistrel Vertical Solutions d.o.o. Podjetje Za Napredne Letalske Resitve, Elringklinger AG

https://heaven-fch-project.eu/

PROJECT AND GENERAL OBJECTIVES

The overall objective of this project was to address the gap between the research and product stages of a zero-emission fuel-cell-based propulsion technology to achieve emission reduction and noise reduction scenarios and meet the 2050 environmental goals for aviation. To that end, a high-efficiency, high-power-density, fuel-cell-based serial hybrid-electric propulsion architecture was combined with the high energy density of cryogenic hydrogen storage. It was advanced up to technology readiness level 6.

NON-QUANTITATIVE OBJECTIVES

- Heaven aimed to increase the credibility of the solution for the propulsion of passenger aircraft and unmanned aerial vehicles.
- The project also aimed to advance towards zero-emission hydrogen-powered regional commuter airliners.

PROGRESS AND MAIN ACHIEVEMENTS

- Manufacturing of cryogenic systems and development of the ground support equipment.
- Testing and verification of the cryogenic system.
- Integration of the powertrain into the aircraft.
- Modification of aircraft system to couple a cryogenic fuel system with the GH2 fuel system.
- Procurement of a permit for flight testing.
- Ground and flight demonstration of HY4 aircraft with liquid hydrogen on board.
- Fuel cell and hydrogen fuel system coupling and testing with liquid hydrogen (March 2023).
- Ground tests (June 2023).
- Flight test (September 2023).

FUTURE STEPS AND PLANS

The project has finished.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objectives and AWP 2018	Power mass density of FC stack	kW/kg	2	2.7 (stack, including end plates)	✓
	Power volume density of FC	kW/l	3.5	4.1 (stack, including end plates)	✓
	Air subsystem	%	> 50	Preliminary results in compliance with this value but not achieved yet	⚙
	Power converter	kW/kg	8	Preliminary results in compliance with this value but not achieved yet	⚙
	System lifetime	hours	500	N/A	⚙
	Hydrogen system	wt%	> 5.5	115	✓

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NIMPHEA

NEXT GENERATION OF IMPROVED HIGH TEMPERATURE MEMBRANE ELECTRODE ASSEMBLY FOR AVIATION

Project ID	101101407
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	HORIZON-JTI-CLEANH2-2022-03-08: Development and optimisation of a dedicated fuel cells for aviation: disruptive next-gen high temperature fuel cells technology for future aviation
Project total costs	EUR 4 942 898.75
FCH JU max. contribution	EUR 4 942 898.50
Project start - end	1.1.2023–31.12.2026
Coordinator	Safran Power Units, France
Beneficiaries	Advanced Energy Technologies AE Ereunas & Anaptyxis Ylikon & Proiontonananeosimon Pigon Energeias & Synafon Symvouleftikon y Piresion, Centre national de la recherche scientifique, Commissariat à l'Énergie Atomique et aux Énergies Alternatives, Fraunhofer Gesellschaft zur Förderung der Angewandten Forschung EV, Fundación IMDEA Energía, Safran SA, Université de Strasbourg

https://www.nimphea.eu/

PROJECT AND GENERAL OBJECTIVES

The overall objective of the Nimphea project is to develop and validate at technology readiness level 4 a new-generation high-temperature membrane electrode assembly (MEA) addressing the challenging requirements of fuel cells for aviation. The MEA developed will operate above 120 °C and thus overcome the thermal management issues of high-power systems.

NON-QUANTITATIVE OBJECTIVES

- Design the concept of the new-generation disruptive MEA operating above 120 °C and develop its components.
- Upscale the small-scale MEA with a view to preparing for manufacturing and future integration at the fuel cell stack level.
- Validate and demonstrate the performances of the new-generation MEA developed at technology readiness level 4.
- Evaluate and validate the suitability of the new-generation MEA by performing a complete life cycle assessment.

PROGRESS AND MAIN ACHIEVEMENTS

The technical specifications have been described for the new Nimphea MEA. The consortium has harmonised its testing strategy for all products. The components of the first-generation MEA have been developed and delivered for its assembly, which will be performed in the coming months.

FUTURE STEPS AND PLANS

The next steps are the assembly and characterisation of the first-generation MEA.

After that, the consortium will start working on developing the second-generation MEA components.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Power density	W/cm^2	1.25	
	Degradation rate	µV/h	3–5	

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BRAVA

BREAKTHROUGH FUEL CELL TECHNOLOGIES FOR AVIATION

Project ID	101101409
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	HORIZON-JTI-CLEANH2-2022-03-06: Development and optimisation of a dedicated fuel cells for aviation – from dedicated stack (100 s kW) up to full system (MWs)
Project total costs	EUR 19 986 841.75
FCH JU max. contribution	EUR 19 986 841.75
Project start - end	1.12.2022–30.11.2025
Coordinator	Airbus Operations GmbH, Germany
Beneficiaries	Airbus Operations SL, Aerostack GmbH, Centre national de la recherche scientifique, Université de Montpellier (affiliate of Centre national de la recherche scientifique), Heraeus Deutschland GmbH & Co. KG, Liebherr-Aerospace Toulouse SAS, Madit Metal SL, Morpheus Designs SL, Rhodia Laboratoire du Futur, Rhodia Operations, Stichting Koninklijk Nederlands Lucht- en Ruimtevaartcentrum, Solvay Specialty Polymers Italy SpA, Technische Universität Berlin

http://brava-project.eu/

PROJECT AND GENERAL OBJECTIVES

- Defining fuel-cell-based power generation system architecture and safety requirements based on the higher-level fuel cell propulsion system requirements (considering balance of weight).
- Designing, developing, testing and validating a two-phase cooling system for fuel cell stacks.
- Designing, developing, testing and validating compact and form-flexible (air to liquid) heat exchangers through additive manufacturing.
- Developing, optimising, testing and validating a high-performance fuel cell stack.
- Developing, testing and validating an air supply subsystem for a fuel cell system for aviation
- Design a fuel cell power generation system with high efficiency and high gravimetric power density compatible with aeronautical specifications and constraints based on the integration of developed subsystems.

NON-QUANTITATIVE OBJECTIVES

Within the scope of BRAVA, we will embark on a preliminary design phase, conceptualising a complete power generation system that seamlessly integrates the various subsystems. While the project's focus remains on subsystem-level advancements, we acknowledge that further integration into a power propulsion system and eventual aircraft-level integration lie outside the project's immediate purview.

The underlying concepts, models, assumptions and methodologies for the fuel cell stack that forms the bedrock of our project work in harmony with developments in the other subsystems (air supply and thermal management systems) to ensure the realisation of BRAVA's overall objectives.

PROGRESS AND MAIN ACHIEVEMENTS

Within BRAVA, the fuel cell subsystems will deliver a range of pivotal project results, revolutionising the future of aviation.

- **2-PC based thermal management system.** Our pioneering thermal management system embraces a 2-PC design, incorporating a newly engineered fuel cell stack. By prioritising compactness and weight reduction, we aim to significantly minimise fuel consumption and maximise efficiency.
- **Advanced head exchangers.** We introduce advanced heat exchanger technology, optimising heat rejection while ensuring seamless integration, reduced weight and minimal aerodynamic drag. This breakthrough innovation contributes to enhanced performance and fuel efficiency.
- **Advanced stack cell catalysts and membranes.** BRAVA pushes the boundaries of stack cell catalysts and membranes, unlocking higher levels of performance and durability, and better operational temperature capabilities. These advancements facilitate the integration of new membrane electrode assemblies that deliver unparalleled efficiency, compactness, reduced weight and extended lifetimes.
- **Innovative air supply architecture.** Our team has meticulously designed and optimised a state-of-the-art air supply architecture, bolstered by components specifically tailored to aviation requirements. This forward-thinking approach minimises parasitic power, reduces weight and ultimately lowers fuel consumption and the cost of equipment.
- **Optimised fuel cell system architecture.** Embracing a holistic approach, BRAVA presents an optimised fuel cell system architecture that encompasses innovative concepts such as anode and cathode path recirculation. These advancements promote compactness, lightweight design and elevated operational reliability, propelling aviation power systems to new heights.

FUTURE STEPS AND PLANS

In our pursuit of excellence, we will utilise a reference system – a robust MW fuel cell power generation system – developed, constructed and tested independently from the BRAVA project. This reference system will serve as the benchmark against which we measure our progress and accomplishments in subsystem development. By surpassing the achievements of the reference subsystems and meeting the key performance indicators defined at an early stage of the project, BRAVA will position itself to carry out a follow-up project, such as in phase 2 of the Clean Aviation programme.

The follow-up project will focus on the development of an integrated fuel cell propulsion system, encompassing both ground and flight testing. This ambitious endeavour will elevate the product specifications and performance of future aviation power generation systems to unprecedented heights. The result will be a revolutionary fuel cell system designed specifically for aviation applications, paving the way for a new era of high-performance, decarbonised flight through hydrogen fuel cell technology.

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COCOLIH_2T

COMPOSITE CONFORMAL LIQUID H_2 TANK

Project ID	101101404
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	HORIZON-JTI-CLEANH2-2022-03-07: Development of specific aviation cryogenic storage system with a gauging, fuel metering, heat management and monitoring system
Project total costs	EUR 8 726 769.50
FCH JU max. contribution	EUR 8 726 769.50
Project start - end	1.2.2023–31.1.2026
Coordinator	Collins Aerospace Ireland Ltd, Ireland
Beneficiaries	Avions de Transport Régional, Crompton Technology Group Ltd, Goodrichhy Aerospace Europe SAS, Microtecnica SRL, Novotech Aerospace Advanced Technology SRL, Simmonds Precision Products Inc. (a part of Collins Aerospace), Stichting Koninklijk Nederlands Lucht- en Ruimtevaartcentrum, Technische Universiteit Delft, Unified International, Utc Aerospace Systems Wroclaw Sp z.o.o.

https://www.cocolih2t.eu/

PROJECT AND GENERAL OBJECTIVES

Improvements to existing state-of-the-art solutions include better utilisation of the available space for fuel storage, adequate insulation techniques to minimise heat leak, continued safe operations and weight reduction through the use of low-weight materials – such as thermoset or thermoplastic composites – all while addressing those materials' inherent challenges (permeability, microcracking, thermal fatigue).

NON-QUANTITATIVE OBJECTIVES

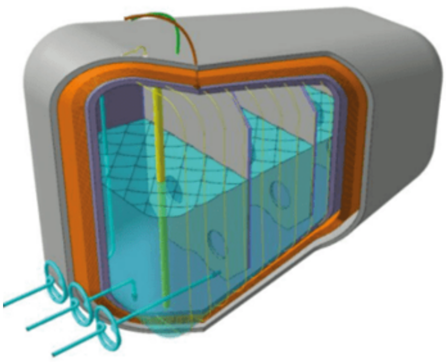
The project aims to push the boundaries of the composite design of liquid hydrogen storage systems, and those of pressure management systems, cryogenic fluid controls, prognostic and structural health systems, hazard analyses, integration and systems testing, gauging sensors, leak sensors and so much more.

PROGRESS AND MAIN ACHIEVEMENTS

- Completion of preliminary and critical design reviews of the Cocolih$_2$t liquid hydrogen storage system.
- Development to technology readiness level 3 of cryogenic valves, prognostic health monitoring algorithms and liquid hydrogen fuel gauging technology.

FUTURE STEPS AND PLANS

A manufacturing readiness review is planned for summer 2024, and the first demonstration system is planned to be shipped from Novotech in Italy to the Netherlands Aerospace Centre before the end of the year.



PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Maximum diameter	m	< 1	
	LH_2 tank capacity	kg	57	
	Boil-off	%/day	< 2	
	Tank gravimetric efficiency	%	0.25	
	Venting rate	%/day	< 2	
	Dormancy	hours	> 24	
	Insulation vacuum	mbar	10^{-5}	

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JIVE

JOINT INITIATIVE FOR HYDROGEN VEHICLES ACROSS EUROPE

Project ID	735582
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	FCH-01-9-2016: Large scale validation of fuel cell bus fleets
Project total costs	EUR 88 391 377.79
FCH JU max. contribution	EUR 32 000 000.00
Project start - end	1. 1. 2017–30. 6. 2024
Coordinator	Environmental Resources Management (ERM) Ltd (previously Element Energy Ltd), United Kingdom
Beneficiaries	Aberdeen City Council, Birmingham City Council, Dundee City Council, EE Energy Engineers GmbH, Element Energy Ltd, ERM France, ESWE Verkehrsgesellschaft MBH, EUE APS, Fondazione Bruno Kessler, Gelderland, Herning Kommune, HyCologne – Wasserstoff Region Rheinland EV, Hydrogen Europe, hySOLUTIONS GmbH, In-Der-City-Bus GmbH, Latvijas Ūdeņraža Asociācija, London Bus Services Ltd, Mainzer Verkehrsgesellschaft mbH, Planet Planungsgruppe Energie und Technik GbR, RebelGroup Advisory BV, Regionalverkehr Köln GmbH, Rigas Satiksme SIA, Societa Autobus Servizi d'Area SpA, Sphera Solutions GmbH, Südtiroler Transportstrukturen AG, Trentino Trasporti SpA, Union Internationale des Transports Publics, Verkehrs-Verbund Mainz-Wiesbaden GmbH, West Midlands Travel Ltd, WSW mobil GmbH

https://www.fuelcellbuses.eu/projects/jive

PROJECT AND GENERAL OBJECTIVES

The JIVE project exists to assist the commercialisation of fuel cell buses (FCBs) as a zero-emission public transport option across Europe. The project aims to address the current high ownership cost of FCBs relative to conventionally powered buses, and the lack of hydrogen refuelling infrastructure across Europe, by supporting the deployment of 131 FCBs in seven locations. This will more than double the number of FCBs currently operating in Europe.

NON-QUANTITATIVE OBJECTIVES

- JIVE aims to demonstrate the suitability and provide experience of FCBs for wider roll-out. Through the publication of project deliverables such as a best practice and commercialisation report, information flows to interested observer parties have been established.
- The project aims to raise awareness of the readiness of fuel cell technology for wider roll-out, with a focus on bus purchasers and regulators. A strong observer group within the JIVE consortium has been established. This group monitors discussions and best practices emerging from the project. This will ensure that the momentum of FCB uptake in Europe continues beyond the project.
- JIVE aims to deliver positive environmental impacts by operating FCBs for extended periods. As per the project's objectives, all buses deployed thus far in the project are replacing diesel technology. This means that the buses will lead to CO_2 abatement and will not simply operate as a visible extra.

PROGRESS AND MAIN ACHIEVEMENTS

- By October 2023, 100 % of buses had started operating in seven cities and four countries. The vehicles represent models from four European bus manufacturers.
- By the end of 2023, the JIVE FCBs had travelled 9 128 925 km across all deployment sites.
- Fuel cells have been operating for a total of 384 555 hours.
- Across all the project's hydrogen refuelling stations, 892 132 kg of hydrogen has been dispensed across 52 677 fills. Please note that the kilograms of hydrogen dispensed and the number of fills include the Cologne and Wuppertal sites, which are involved in both JIVE and Joint initiative for hydrogen vehicles across Europe 2 (JIVE 2).

FUTURE STEPS AND PLANS

- All buses are expected to be operational.
- To date, only one city does not yet have operational buses.
- Uncertainties around ongoing issues related to hydrogen supply (undelivered hydrogen, hydrogen prices, etc.) are expected to be clarified in the upcoming period to ensure that all buses are fully in service.
- By the end of the project, it is expected that the total distance travelled will be 10 683 714 km.
- The total number of fuel cell hours by the end of the project is expected to be 414 253.
- Hydrogen refuelling stations involved in JIVE are projected to dispense 1 055 089 kg of hydrogen across 61 898 individual fills.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objectives	Vehicle operational lifetime	years	8	N/A	
	Distance travelled	km/year	> 44 000	N/A	
	Availability	%	> 90	85.1	
	MDBF	km	> 2 500	N/A	⚙
	Efficiency	%	> 42	N/A	
	Vehicle OPEX	€	≤ 100 % more than diesel bus OPEX	N/A	
	Operating hours per fuel cell system	hours	> 20 000	N/A	
	Specific fuel consumption	kg / 100 km	< 9.0	7.56	✓
	Vehicle CAPEX	€	< 650 000	N/A	

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JIVE 2

JOINT INITIATIVE FOR HYDROGEN VEHICLES ACROSS EUROPE 2

Project ID	779563
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	FCH-01-5-2017: Large scale demonstration in preparation for a wider roll-out of fuel cell bus fleets (FCB) including new cities' – phase two
Project total costs	EUR 89 972 571.29
FCH JU max. contribution	EUR 25 000 000.00
Project start - end	1.1.2018–30.6.2025
Coordinator	Environmental Resources Management (ERM) Ltd (previously Element Energy Ltd), United Kingdom
Beneficiaries	Brighton & Hove Bus and Coach Company Ltd, Communauté d'agglomération de l'auxerrois, Connexxion Openbaar Vervoer NV, Connexxion Vloot BV, Dundee City Council, EE Energy Engineers GmbH, Element Energy, Element Energy Ltd, ENGIE Energie Services, ERM France, Hydrogen Europe, Hyport, Kolding Kommune, Landstinget Gavleborg, Messer SE & Co. KGaA, Mestna občina Velenje, Noord-Brabant Provincie, Občina Šoštanj, Openbaar Lichaam OV-Bureau Groningen en Drenthe, Pau Béarn Pyrénées Mobilités, Petrogal SA, Provincie Zuid-Holland, RebelGroup Advisory BV, Regionalverkehr Köln GmbH, Rheinische Bahngesellschaft AG, Rīgas satiksme, Ruter AS, Société publique locale d'exploitation des transports publics et des services à la mobilité de l'agglomération paloise, Sphera Solutions GmbH, Straeto BS, Transdev Occitanie Ouest, Transports de Barcelona SA, Twynstra Gudde Mobiliteit & Infrastructuur BV, Union Internationale des Transports Publics, Vatgas Sverige Ideell Forening, WSW mobil GmbH, Zerobus OÜ

https://www.fuelcellbuses.eu/projects/jive-2

PROJECT AND GENERAL OBJECTIVES

The JIVE 2 project aims to deploy 156 fuel cell buses (FCBs). Combined, the JIVE projects will deploy nearly 300 FCBs in 16 cities across Europe – the largest deployment in Europe to date.

NON-QUANTITATIVE OBJECTIVES

- JIVE 2 aims to demonstrate the suitability and provide experience of FCBs for wider roll-out. Through the publication of project deliverables such as a best practice and commercialisation report, information flows to interested observer parties have been established.
- The project aims to raise awareness of the readiness of fuel cell technology for wider roll-out, with a focus on bus purchasers and regulators. A strong observer group within the JIVE consortium has been established. This group monitors discussions and best practices emerging from the project. This will ensure that the momentum for the FCB uptake in Europe continues beyond the project.
- JIVE 2 aims to deliver positive environmental impacts by operating FCBs for extended periods. As per the project objective, all buses deployed thus far in the project are replacing diesel technology. This means that the buses will lead to CO_2 abatement and will not simply operate as a visible extra.

PROGRESS AND MAIN ACHIEVEMENTS

- To date, 122 buses have been ordered.
- To date, 98 buses have begun to operate, which represents 63 % of all the planned buses.
- To date, one site has been operating its FCBs for more than 3 years.
- In 2023, JIVE 2 FCBs travelled a total of 8 076 892 km.
- JIVE 2 fuel cells operated for 211 231 hours.
- At JIVE 2 hydrogen refuelling stations, 451 455 kg of hydrogen was dispensed across 29 229 individual fills.

FUTURE STEPS AND PLANS

- By the second quarter of 2023, all buses were ordered.
- By the third quarter of 2024, all buses will have been delivered and put into operation. To date, only one site does not yet have its buses in operation.
- By the end of the project in 2025, it is estimated that JIVE 2 FCBs will have travelled 15 522 872 km. The fuel cells are estimated to have been in operation for 314 932 hours.
- By the end of the project in 2025, it is estimated that the project's hydrogen refuelling stations will have dispensed 868 373 kg of hydrogen across 53 313 fills.
- It is expected by the end of the project that fuel consumption objectives will have been met by both the 12 m and the 18 m FBCs involved in the project.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objectives	Vehicle operational lifetime	years	8	N/A	
	Ensure availability >90%	%	90	<=80%	
	Distance travelled	km/year	> 50 000	27 627.3	
	Operating hours per fuel cell system	hours	> 20 000	2 014.81	
	Availability	%	> 90	82.3	
	Efficiency	%	> 42	N/A	
	Vehicle OPEX	€	≤ 100 % more than diesel bus OPEX	N/A	
	MDBF	km	> 3 500	10 242	
	Specific fuel consumption	kg / 100 km	< 9.0	7.49	✓
	Vehicle CAPEX	€	< 625 000	N/A	

H_2ME 2

HYDROGEN MOBILITY EUROPE 2

Project ID	700350
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	FCH-03.1-2015: Large scale demonstration of hydrogen refuelling stations and FCEV road vehicles – including buses and on site electrolysis
Project total costs	EUR 106 490 818.38
Clean H_2 JU max. contribution	EUR 34 999 548.50
Project period	1.5.2016–31.12.2023
Coordinator	Environmental Resources Management (ERM) Ltd, United Kingdom
Beneficiaries	AGA AB, Air Liquide Advanced Business, Air Liquide Advanced Technologies SA, Air Liquide France Industrie, Alphabet Fuhrparkmanagement GmbH, Audi AG, B. Kerkhof & Zn. BV, Bayerische Motoren Werke AG, Brintbranchen, Centre of Excellence for Low Carbon and Fuel Cell Technologies, Communauté Urbaine du Grand Nancy, Compagnie Nationale du Rhône SA, Daimler AG, Eifer Europäisches Institut für Energieforschung EDF KIT EWIV, Element Energy, ERM UK, Elogen, ERM France, GNVERT SAS, H2 Mobility Deutschland GmbH & Co. KG, Honda Motor Europe Ltd, Honda R&D Europe (Deutschland) GmbH, Hydrogene De France SA, Hydrogène Grand Ouest, HYOP AS, Hype, Hype Assets, Hysetco, Hysolutions GmbH, HYSSY, Icelandic New Energy Ltd, Intelligent Energy Ltd, Íslenska Vetnisfélagið EHF, ITM Power (Trading) Ltd, Københavns Kommune, Linde Gas GmbH, Manufacture Française des Pneumatiques Michelin, McPhy Energy, McPhy Energy Italia SRL, Mercedes-Benz AG, Mercedes-Benz Fuel Cell GmbH, Ministerie van Infrastructuur en Waterstaat, Nel Hydrogen AS, Nel Hydrogen Electrolyser AS, Nissan Motor Manufacturing (UK) Ltd, Open Energi Ltd, Renault SAS, Renault Trucks SAS, Reseau GDS, R-Hynoca, Société d'économie mixte des transports en commun de l'agglomération nantaise, Stedin Diensten BV, Stedin Netbeheer BV, Stichting Cenex Nederland, Symbio, Tech Transports Compagnie, University of Manchester, Toyota Danmark AS, Toyota Norge AS, Waterstofnet VZW

www.h2me.eu

PROJECT AND GENERAL OBJECTIVES

H_2ME 2 brings together actions in eight countries in a 7-year collaboration to deploy 20 hydrogen refuelling stations (HRSs) and > 1 100 vehicles. The project has performed a large-scale market test of a large fleet of fuel cell electric vehicles operating in real-world customer-focused environments across multiple European regions. In parallel, it has demonstrated that the hydrogen mobility sector can support the wider European energy system through electrolytic hydrogen production.

Prior to H_2ME, there were few large deployments of fuel cell hydrogen vehicles in Europe. The H_2ME projects have contributed to deploying one third of fuel cell hydrogen vehicles on the road and 20 % of HRSs open today in Europe. In addition, H_2ME has encouraged application to other types of vehicles (including buses and trucks) by supporting the construction of HRSs.

NON-QUANTITATIVE OBJECTIVES

- More than 1 100 fuel cell vehicles and 20 HRSs will be deployed by the end of the project.
- The project aims to demonstrate the electrolyser-integrated HRS operating to allow grid balancing. H_2ME 2 includes a dedicated work package to assess the way in which electrolytic hydrogen production in the mobility sector can link to the wider energy system.
- Multiple original equipment manufacturers (OEMs) supply vehicles, including cars and utility vehicles. H_2ME 2 aimed to deploy cars and light-duty vans from OEMs including Mercedes, Honda, Symbio, Hyundai and Toyota.
- H_2ME 2 aimed to ensure the circulation of knowledge acquired in the project. A dedicated work plan and dissemination and exploitation plan were developed to achieve this. Three observer countries are included in the project coalition.

PROGRESS AND MAIN ACHIEVEMENTS

- All 20 HRSs planned for the project had been commissioned and were in operation by the end of the project. Combined with the HRS deployed in H_2ME, this constitutes the first step in constructing a European infrastructure network.
- Over 1 100 vehicles were deployed in H_2ME 2. Further deployment and collaboration are expected beyond the end of the project.
- Demonstration in real-world operation started in 2015 – carried out jointly with H_2ME – for over 1 400 vehicles from five OEMs (Mercedes, Honda, Hyundai, Symbio and Toyota) across eight countries and 50 HRSs from 10 suppliers across six countries (Denmark, France, Iceland, the Netherlands, Sweden and the United Kingdom).
- The fuel cell electric vehicles worked reliably, with new models offering increased performance becoming available on the market.
- The project generated a vast base of operational data from vehicles and HRSs, and involved further fact-based analyses of vehicles' and HRSs' performance. Since 2015, > 40 million kilometres have been driven and 915 t of H_2 distributed in 360 000 events (figures from January 2024).
- Green mass mobility and logistics solutions were proven to be effective in cities and regions, with ranges and refuelling times similar to those of conventional vehicles. The experience gained gives a robust springboard for further roll-outs.
- Across H_2ME and H_2ME 2, around 100 reports were prepared, with the majority publicly available on the project's website.

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
HRSs							
Project's own objectives, MAWP addendum (2018–2020) and AWP 2015	Minimum period of HRS operation	months	36	58	✓	32	2017
	HRS availability	%	98	96		98	2017
	Hydrogen purity	%	99.99	99.99	✓	99.99	2017
FC vehicles							
Project's own objectives, MAWP addendum (2018–2020) and AWP 2015	Minimum period of vehicle operation during project	months	36	60	✓	12	2017
	Vehicle availability	%	98	Around 100	✓	98	2017

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ZEFER

ZERO EMISSION FLEET VEHICLES FOR EUROPEAN ROLL-OUT

Project ID	779538
PRR 2024	Pillar 3 – H_2 end uses: transport
Call topic	FCH-01-6-2017: Large scale demonstration of hydrogen refuelling stations and fuel cell electric vehicle (FCEV) road vehicles operated in fleet(s)
Project total costs	EUR 13 676 254.48
FCH JU max. contribution	EUR 4 998 843.00
Project start - end	1.9.2017–31.8.2023
Coordinator	Environmental Resources Management Ltd, United Kingdom
Beneficiaries	Air Liquide Advanced Business, Air Liquide Advanced Technologies GmbH, Air Liquide Advanced Technologies SA, Air Liquide France Industrie, Bayerische Motoren Werke AG, Breath, Centre of Excellence for Low Carbon and Fuel Cell Technologies, DRIVR Danmark AS, Element Energy, Element Energy Ltd, Environmental Resources Management France, Green Tomato Cars Ltd, Hype, ITM Power (Trading) Ltd, Air Liquide Belge, Linde AG, Linde GmbH, Mayor's Office for Policing and Crime (UK), Toyota Danmark AS, City of Paris

https://zefer.eu/

PROJECT AND GENERAL OBJECTIVES

The ZEFER project aimed to demonstrate the feasibility of hydrogen mobility from a technical and financial perspective, and hence to accelerate the roll-out of vehicles and hydrogen refuelling infrastructure across Europe. Through the project, the ZEFER partners aimed to:

- deploy 180 fuel cell passenger cars in fleet operations across three major cities in Europe: Paris, Copenhagen and London;
- test the performance of fuel cell electric vehicles (FCEVs) in high-mileage fleets, travelling millions of kilometres over the project period;
- prove that the fleet operation of FCEVs is a viable business model for high-mileage fleets in urban areas, bringing potential savings to the fleet operator when the externalities of choosing a zero-emission vehicle over an incumbent diesel vehicle are considered;
- gather data on the performance of FCEVs as high-mileage fleet vehicles to provide an evidence base that these vehicles are reliable and suitable to be deployed in major cities around Europe, and across the world;
- increase the utilisation of hydrogen refuelling systems (HRSs) to demonstrate the viable business models for early HRSs supported by captive fleets;
- test the performance of today's best-in-class hydrogen refuelling station technology under significantly increased loads compared with current levels, which will help to highlight the reliability of the stations and their ability to meet the demands of a growing number of FCEVs on the road;
- communicate the benefits of FCEVs in fleet operation through the widespread dissemination of the technical and business modelling research results, targeting decision-makers to initiate conversations in local authorities and to foster the acceptance of FCEV fleets.

NON-QUANTITATIVE OBJECTIVES

- The project aimed to increase the confidence of investors and policymakers in FCEV and HRS roll-out. Analysis in ZEFER has proven that FCEVs and HRSs can meet the demands of high-mileage fleet operations. This has led to fleet operators increasing the number of FCEVs in their fleets. It has also attracted investors.
- Six out of the 15 ZEFER partners are small or medium-sized enterprises (SMEs). In particular, the three largest fleet operators are SMEs, and therefore a large proportion of ZEFER's funding (84 %) is allocated to SMEs.
- ZEFER aimed to reduce the production cost of fuel cell systems to be used in transport applications, while increasing their lifetimes to compete with conventional technologies.
- The project aimed to increase the energy efficiency of hydrogen production while reducing operating and capital costs so that the combined system can compete with alternatives on the market. ZEFER aimed to reduce the hydrogen cost at the pump. This could be achieved by providing a stable demand for hydrogen at an HRS. The project also aimed to trigger further cost reductions by creating a climate of investment in the low-cost green production systems required to drive the overall cost below this level.

PROGRESS AND MAIN ACHIEVEMENTS

- 180 FCEVs have been deployed in Paris (Hype), London (GTC and the Metropolitan Police) and Copenhagen (DRIVR).
- The ZEFER vehicles in service have been operated rigorously in everyday operation and had driven over 15 million kilometres as of August 2023.
- All HRS upgrades necessary to support the deployment of FCEVs in the project have been completed.
- HRSs in France (Air Liquide), in the United Kingdom (ITM Power) and in Denmark (Nel) had dispensed 149 000 kg of H_2 to ZEFER vehicles as of June 2023.
- The peak of number of data-reporting vehicles (104) was reached in the second quarter of 2022, thanks to the increase in vehicles through DRIVR's deployment in Copenhagen alongside Hype's and GTC's deployments.
- The project was successfully completed, with an immense dataset collected for the FCEVs and HRSs in operation.
- ZEFER contributed to increasing the awareness of the business case for FCEVs in fleet applications. Following the project, there was an increase in taxi projects in Europe.

FUTURE STEPS AND PLANS

The project has finished.

Hype continued in Paris. Hype is in the process of deploying additional vehicles in Paris with a fleet of 350 FCEVs overall at the beginning of 2024 and the objective of further expanding their operation in Paris to other European locations. The presence of these vehicles is, however, still most significant in Paris, with an associated distribution network of 26 stations to fuel the vehicles. Plans are also already in place for Hype to replicate the taxi business model in seven other cities in Europe: Le Mans, Bordeaux, Brussels, Madrid, Barcelona, Lisbon and Porto.

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ZEFER

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
FCEVs							
Project's own objectives	Minimum distance for vehicles	km/vehicle	90 000 (60 000 for those deployed in Copenhagen)	A strict KPI km per vehicle was hard to achieve given the challenges faced by the project, and therefore it was agreed that the average number across all ZEFER vehicles would be considered	✓	FCEVs in taxi operations in H_2ME drive on average around 45 000 km per year	2020
	Vehicle availability	%	> 98	> 99 %		> 99 %	2021
	Range	km	500	470 km in Mirai generation 1 and 530 km in Mirai generation 2		756	2020
HRSs							
Project's own objectives	Hydrogen purity	%	99.99	99.99	✓	99.99	2020
	Level of back-to-back vehicle refuelling	number of refuelling events per hour	6	6		6	2020
	HRS availability	%	> 98	96.2 %		98	2016
	Cost of hydrogen	€/kg	10	The project pump price target of € 10 / kg has not been achieved because of the energy crisis.		10	2020

IV. PILLAR 4 – H2 END-USES: CLEAN HEAT AND POWER

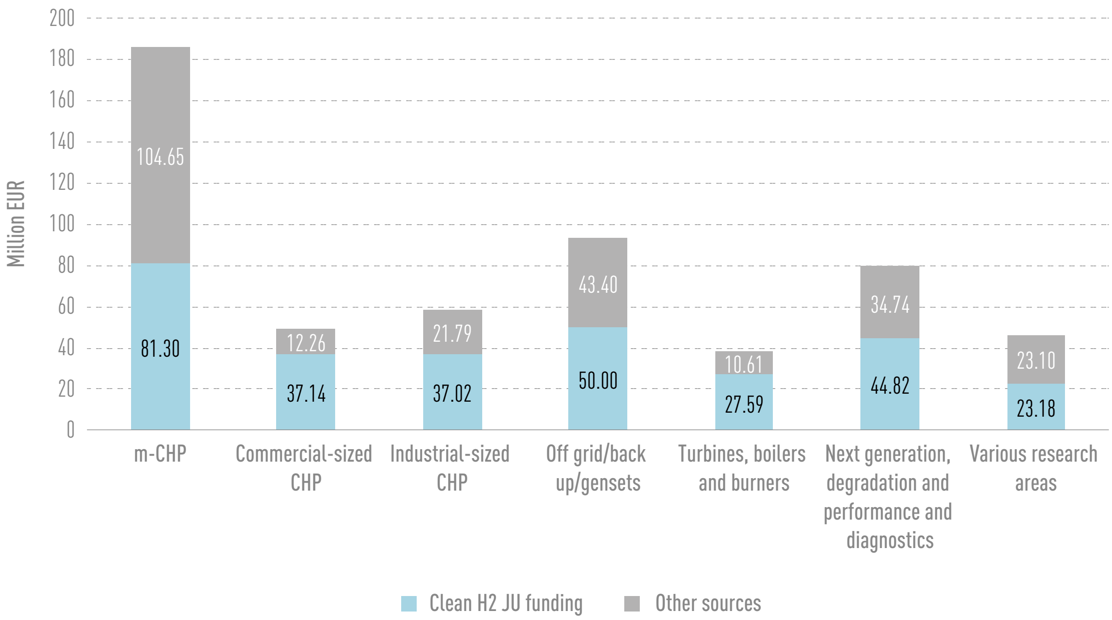
OBJECTIVES: Stationary FC systems for power and CHP generation, as well as for provision of back-up power solutions, still need additional development and larger production volumes to allow competition with well-established traditional systems. The aim is to reduce investment and operational costs whilst improving system durability.

The research areas considered for the 2024 programme review are:

1. **micro-CHP**: 1 project dealing with the use of both PEMs and SOFCs for micro-cogeneration in the residential and small building sectors;
2. **commercial-sized CHP:** 5 projects related to the use of SOFCs and HT PEMFCs for commercial buildings and service sectors;
3. **industrial-sized CHP:** 3 projects targeting reversible solid oxide and PEMFC technologies for industrial applications;
4. **off-grid/back-up/gensets**: 3 demo projects exploring the application of PEM, solid oxide and alkaline hydrogen technologies (FCs and electrolysers) for off-grid applications;
5. **turbines, boilers and burners**: 6 projects focusing on using existing infrastructure – gas turbine combustors and boiler burners – to burn mixtures of hydrogen, ammonia and NG;
6. **next generation, degradation and performance and diagnostics:** 2 projects dedicated to the use of biogas for SOFC CHP systems and use of electrochemical impedance spectroscopy technology for monitoring and diagnostic purposes;
7. **various research areas:** no projects are included in this review.

OPERATIONAL BUDGET: Between 2008 and 2024, the FCH, FCH 2 and Clean Hydrogen JUs have supported 87 projects relevant to pillar 4 with a total JU contribution of EUR 301 million and a contribution from partners of EUR 251 million. Figure 28 indicates that 52 % of the JU funding went to support CHP-related projects – micro-, industrial- and commercial-sized CHP – while the rest was allocated mainly to off-grid demos (16.6 %) and next generation, degradation and performance and diagnostics (14.8 %). In addition, two projects covering turbines, boilers and burners started in 2023 and accounted for around 9 % of the total JU funding. The overall JU funding contribution amounts to about 55 % of the total funding for the portfolio of projects under this pillar since 2008.

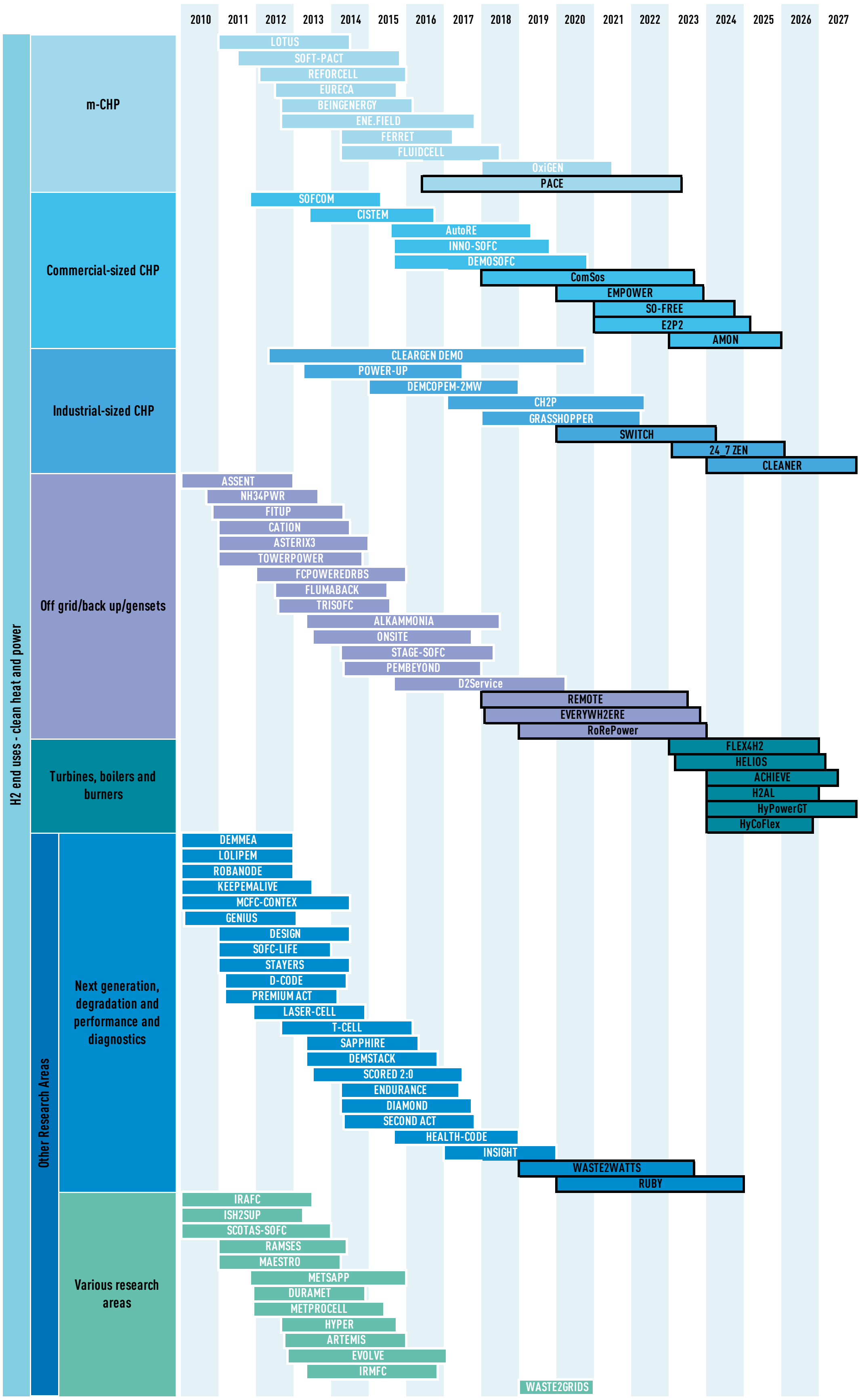
Figure 37: Funding for pillar 4 projects from 2008 to date



Source: Clean Hydrogen JU.

PROJECTS IN BRIEF: Out of the 20 projects in the current review, 8 focus solely on SOFC technology and 2 involve both solid oxide and LT PEM technologies. LT PEMFCs are addressed in 3 projects, and HT FCs are the focus of 1 project. In 2023 and 2024, 6 new projects within the turbines, boilers and burners research area have been initiated. Figure 28 shows the pillar 4 projects, grouped by research area.

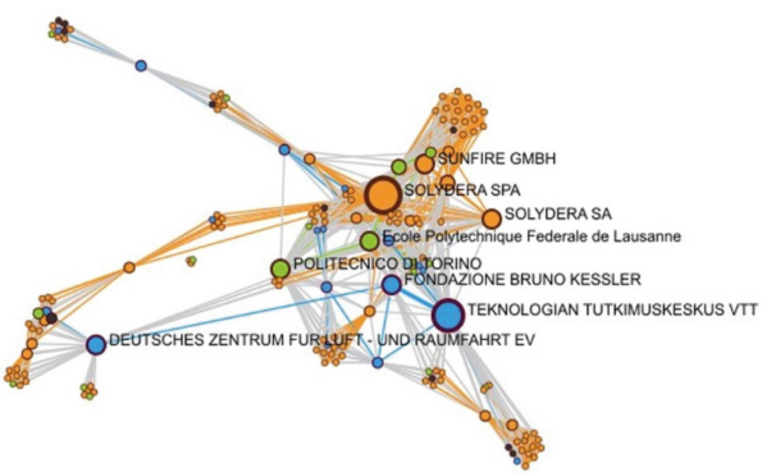
Figure 38: Project timelines for pillar 4 – H2 end-uses – clean heat and power



Source: Clean Hydrogen JU.

Figure 39 shows that many projects are strongly linked to each other. The key partners present in multiple projects in pillar 4 are the FC stack/system providers (SolydEra, previously called SolidPower, and Sunfire) and the research institute, VTT. As these projects are higher-TRL demonstration projects, it is obvious that private companies dominate participation. Italy, Germany, France, the Netherlands, Belgium and Finland are the most active Member States in this domain (Figure 40).

Figure 39: TIM plot showing entities' participation in pillar 4 projects

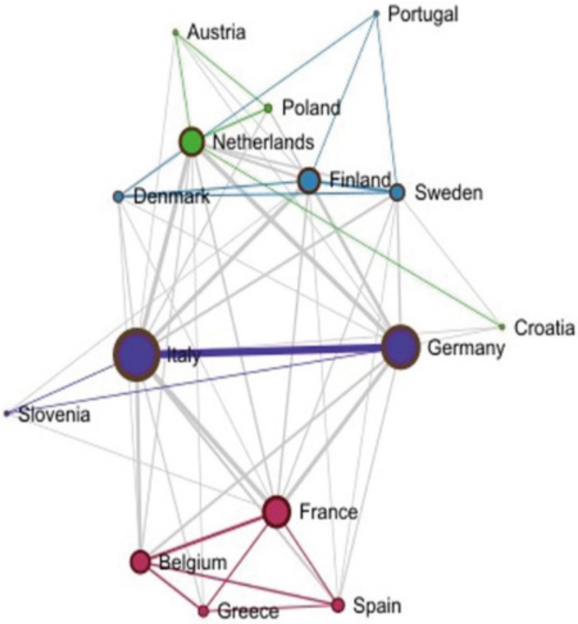


Top Participants

Participant	Number of Projects
SOLYDERA SPA	8
TEKNOLOGIAN TUTKIMUSKESKUS VTT	7
Multiple participants	4

Source: TIM, JRC, 2024.

Figure 40: TIM plot showing EU Member State participation in pillar 4 projects



Member State	Number of Projects
Italy	17
Germany	14
France	10
Netherlands	9
Belgium	8
Finland	8

Source: TIM, JRC, 2024.

Micro-CHP

PACE, following up on the ENEFIELD project, is a large-scale initiative deploying 2 674 residential FC m-CHP installations in 10 European countries.

Commercial-sized CHP

COMSOS aimed to validate and demonstrate FC-based CHP solutions using NG in the mid-sized power ranges of 10-12 kW, 20-25 kW and 50-60 kW (referred to as mini-FC CHP). A total of 321 kWe of SOFC power was installed in customer locations. In total, five units with total power capacity of 112 kW were installed in the EU and seven units with total power capacity of 209 kW were installed in China (1 unit), Taiwan (5 units) and the US (1 unit).

E2P2 aims to develop and demonstrate low-environmental-impact FCs for prime-power solutions in data centres and other critical infrastructure, targeting the European market. The E2P2 system set-up will consist of 2×45 kW FC units.

SO-FREE will develop a future-ready SOFC-based system for CHP generation. SO-FREE also aims to establish a standardised stack-system interface. This interface will ensure full interchangeability of SOFC stack types within a given SOFC CHP system.

EMPOWER involved the development, manufacturing and validation of a 5 kWe mini-CHP system powered by a methanol-fuelled, HT, polymer electrolyte membrane FC technology.

AMON aims to create a novel system for ammonia utilisation and conversion into electricity at high efficiency through an SOFC system. It will also validate the compatibility of all specific parts and components with ammonia use.

Industrial-sized CHP (above 100 kW)

SWITCH developed a new reversible hydrogen production system using rSOC technology, which can adapt to the intermittent nature of renewable energy by quickly switching between electrolysis and FC operation modes. Additionally, the system's flexibility, which allows for the use of various energy carriers and a focus on mobility due to its reversibility, is a significant advantage. The system is more efficient, cost-effective and environmentally friendly than traditional methods. The prototype system consists of an rSOC unit developed in the SWITCH project and two SOFC units developed in the CH2P project.

24/7 ZEN aims to design, construct and validate a versatile rSOC plant that generates 33 kW of electric power using SOFCs and injects/stores 100 kW in the form of H_2. A containerised, plug-and-play rSOC solution will be compatible with both grids and equipped for off-grid settings.

CLEANER aims to develop and demonstrate a PEMFC system with a capacity of more than 100 kW that will operate for over 5 000 hours on industrial-quality hydrogen, thus significantly reducing operational costs through the development of lower-cost, impurity-tolerant catalyst materials and new fluorine-free membranes.

Off-grid/back-up/gensets

REMOTE effectively demonstrated three hydrogen-based P2P systems out of four that were initially planned, based on H2 battery systems in various EU locations.

RoRePower had as its objective to create and showcase SOFC systems for continuous off-grid power generation in challenging climatic conditions (-40 to +50 °C). The project aimed to achieve a 30-40 % reduction in total manufacturing, BoP component procurement and system costs. The project has successfully installed 50 demonstration units.

EVERYWH2ERE aimed to demonstrate hydrogen FC generators at various events and locations across the EU, promoting their potential and increasing social acceptance.

Turbines, boilers and burners

FLEX4H2 aims to design, develop and validate a highly fuel-flexible sequential combustion system capable of operating with any hydrogen concentration mixed with NG up to 100 % at H-class operating temperatures. The project is based on Ansaldo Energia's proprietary constant pressure sequential combustion technology, which has already been implemented in a GT36 H-class engine (760 MW in a combined cycle).

HELIOS aims to develop safe hydrogen combustion technology as a retrofit solution, which will allow end-users to extend the lifespan of their existing assets, reducing additional costs and environmental impact associated with new installations. The solution is based on the FlameSheet combustor from Ansaldo Thomassen B.V. The challenge lies in the significantly different combustion characteristics of hydrogen and NG, especially for low-NOx premixed hydrogen combustion.

ACHIEVE aims to facilitate the reduction of pollutant gases (CO2 and NOx) from current and future gas turbine systems by establishing a comprehensive knowledge base and validating (TRL 4) solutions for the combustion of unconventional hydrogen blends in gas turbines, including mixtures of hydrogen, ammonia, methane, nitrogen and water vapour. This focus aims to enhance the efficiency and cleanliness of gas turbine operations.

H2AL is focused on tackling the difficulties of incorporating hydrogen in hard-to-abate industries, in particular the aluminium scrap recycling sector, through a combined strategy involving digital tools and cutting-edge experimental methods. Ultimately, the goal is to integrate, demonstrate and evaluate a 0-100 % H2 combustion system in aluminium production at 2A s.p.a. facilities. The system includes new burner technology (to be produced by Nippon), refractory materials, sensing and furnace retrofit approaches and the digital supporting tools developed during the project to improve the processes.

HyPowerGT aims to expand technology boundaries, enabling gas turbines to operate on hydrogen without dilution. The core technology is a novel dry low emission combustion system designed to handle mixtures of NG and hydrogen with concentrations of up to 100 % H2. The combustion technology will be refined, matured and demonstrated at TRL 7 on a 16.9 MWe gas turbine engine (NovaLT16) fired with fuel blends mixed with hydrogen concentrations ranging from 0-100 %. A digital twin will be developed to simulate performance and durability characteristics, mirroring the cyclic operations of a real cogeneration plant in the Italian paper industry.

HyCoFlex is focused on the development of a retrofittable decarbonisation package for the cogeneration of power and industrial heat using 100 % hydrogen-fired gas turbines. The solution will be integrated and fully demonstrated at an industrial site in Saillat-sur-Vienne, France.

Other research areas

WASTE2WATTS aimed to design an integrated biogas SOFC CHP system with minimal gas pre-processing, developing two cleaning methods and hardware for small-scale (50 kWe) and medium-to-large-scale (≥ 500 kWe) units.

RUBY's objective is to develop and implement a tool capable of performing integrated MDPC functions for SOFC- and PEMFC-based m-CHP and back-up systems. The tool's key feature is the electrochemical impedance spectroscopy-based advanced monitoring of SOFC and PEMFC stacks. RUBY will integrate hardware with diagnostic and control algorithms for the stack, as well as fault detection algorithms for BoP.

PROJECT FACTSHEETS PILLAR 4

Micro-CHP

PACE

Commercial-sized CHP

COMSOS
E2P2
SO-FREE
EMPOWER
AMON

Industrial-sized CHP (above 100 kW)

SWITCH
24/7 ZEN
CLEANER

Off-grid/back-up/gensets

REMOTE
RoRePower
EVERYWH2ERE

Turbines, boilers and burners

FLEX4H2
HELIOS
ACHIEVE
H2AL
HyPowerGT

Other research areas

WASTE2WATTS
RUBY

PACE

PATHWAY TO A COMPETITIVE EUROPEAN FC MCHP MARKET

Project ID	700339
PRR 2024	Pillar 4 – H_2 end uses: stationary application
Call topic	FCH-02.9-2015: Large scale demonstration µCHP fuel cells
Project total cost	EUR 91 681 934.33
Clean H_2 JU max. contribution	EUR 33 932 752.75
Project period	1.6.2016–30.4.2023
Coordinator	European Association for the Promotion of Cogeneration VZW, Belgium
Beneficiaries	Baxi Innotech GmbH, BDR Thermea Group BV, Bosch Thermotechnik GmbH, Danmarks Tekniske Universitet, Element Energy Limited, Environmental Resources Management France, EWE AG, Fachhochschule Zentralschweiz – Hochschule Luzern, HEXIS AG, HEXIS GmbH, New Enerday GmbH, Remeha BV, Remeha GmbH, Remeha NV, SenerTec Kraft-Wärme Energiesysteme GmbH, Solidpower GmbH, SolydEra SpA, Sunfire GmbH, Vaillant GmbH, Viessmann Climate Solutions SE, Viessmann Elektronik GmbH, Viessmann Werke Allendorf GmbH, Viessmann Werke GmbH & Co. KG

http://www.pace-energy.eu

PROJECT AND GENERAL OBJECTIVES

PACE unlocked the large-scale European deployment of the state-of-the-art smart energy solution for private homes: fuel cell micro-cogeneration. PACE aimed to see up to 2 650 households across Europe reaping the benefits of this home energy system. The project enabled manufacturers to move towards product industrialisation and fostered market development at the national level by working together with building professionals and the wider energy community. The project used modern fuel cell technology to produce efficient heat and electricity at home, empowering consumers in their energy choices.

NON-QUANTITATIVE OBJECTIVES

Deploy new manufacturing processes to increase capacity.

Develop efficient routes to market, including innovation in sales, marketing and consumer offers.

Provide efficient field support.

Identify potential revenue streams from participation in the power markets and the economic added value of the avoidance of grid expansions.

Develop a platform approach to component standardisation for fuel cell micro combined heat and power (CHP) across the EU supply chain.

Create the conditions for expansion of the market for fuel cell micro-CHP across Europe.

Increase awareness in European markets of micro-CHP fuel cells.

PROGRESS AND MAIN ACHIEVEMENTS

A total of 2 674 units were commissioned (3 095 units sold) by the end of April 2023.

The project has increased the lifetime of the system to 15–20 years and improved the maintenance interval using new/improved components. The system (excluding stack) lifetime was 10–15 years at the start of project; this increased to a minimum of 15 years by the end of the project.

By the end of the project, all partners virtually eliminated the need for stack replacement during a customer's 10-year service plan (the worst case is 7 years at the project's start).

FUTURE STEPS AND PLANS

The project has finished.

Establish an alliance that will gather major European manufacturers in the area of stationary fuel cells and other relevant industry and research stakeholders to develop evidence and advocacy, with a view to promoting this solution at the EU level and supporting national initiatives.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SOA result achieved (by others)	Year in which SOA result was reported
Project's own objectives	Units sold	number	2 800	3 091	✓	1 046	2017
	Time before stack replacement	years	10-year system lifetime with > 50 % reduction in stack replacement or no stack replacement during a 10-year service plan	15-year system lifetime with > 50 % reduction in stack replacement or no stack replacement during a 10-year service plan	✓	N/A	N/A
	Manufacturing capacity (average at the company level)	units per year per OEM	1 000	2 300	✓	150	N/A
	Availability	%	99	96.2–99	⚙	99	2017

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COMSOS

COMMERCIAL-SCALE SOFC SYSTEMS

Project ID	779481
PRR 2024	Pillar 4 – H_2 end uses: stationary application
Call topic	FCH-02-11-2017: Validation and demonstration of commercial-scale fuel cell core systems within a power range of 10–100 kW for selected markets/applications
Project total cost	EUR 10 277 897.50
Clean H_2 JU max. contribution	EUR 7 486 954.75
Project period	1.1.2018–31.8.2023
Coordinator	Teknologian tutkimuskeskus VTT Oy, Finland
Beneficiaries	Convion Oy, Energy Matters BV, Politecnico di Torino, Solidpower GmbH, SolydEra SA, SolydEra SpA, Sunfire GmbH

https://www.comsos.eu/

PROJECT AND GENERAL OBJECTIVES

The key objective of the Comsos project was to validate and demonstrate fuel-cell-based combined heat and power solutions in the medium-sized power ranges of 10–12 kW, 20–25 kW and 50–60 kW (referred to as mini fuel cell combined heat and power (mini-FC-CHP) solutions. The core of the project consortium consisted of three solid oxide fuel cell (SOFC) system manufacturers aligned with individual strategies along the value chain: Solidpower (SolydEra), Sunfire and Convion.

NON-QUANTITATIVE OBJECTIVES

The overall objectives of the Comsos project were as follows:

- demonstrate and validate a mini-FC-CHP solution;
- promote the worldwide leadership of the EU in the mini-FC-CHP market;
- leverage micro-CHP volumes and cost reductions in additional fuel cell applications;
- confirm the presence of investment opportunities for additional job creation for mini-FC-CHP solutions.

PROGRESS AND MAIN ACHIEVEMENTS

During the project, 321 kWe of SOFC power was installed in customer sites when the requirement was 450 kWe. Sunfire (150 kWe) and Convion (120 kWe) reached the installation target but SolydEra did not (51 kWe). However, an additional 81 kWe of SOFC power was constructed by SolydEra but not installed in customers' sites before the end of the project. These already-constructed units were planned to be installed in customer sites after the project. Total SOFC power constructed during the project was therefore around 400 kWe. In addition, not all installed units achieved 9 000 demonstration hours, but at least one unit from each manufacturer could have reached the 9 000-hour requirement if end users had run the systems all the time. However, for an unknown reason some end users shut down the systems every now and then. For these users, the 9 000-hour target was not always reached in practice, even if from the point of view of the system it was possible.

- All five Sunfire systems (150 kW) were installed at customers' sites.
- Both Convion systems (120 kW) were installed at a customer's site.
- The first three Solidpower (SolydEra) systems (51 kW) were installed at a customer's site.

Each unit type from the manufacturers fulfilled the performance and emission targets of the Comsos project: an electrical efficiency greater than 50 % and NOx emissions lower than 40 mg/kWh.

FUTURE STEPS AND PLANS

The project has finished.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
MAWP (2014–2020)	Electrical efficiency	%	> 50	> 50	✓
	NOx emissions	mg/kWh	< 40	< 40	✓
	Durability	years of plant operation	10	2	
Project's own objectives	SME participation	%	25	50	✓

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E2P2

ECO EDGE PRIME POWER

Project ID	101007219
PRR 2024	Pillar 4 – H_2 end uses: stationary application
Call topic	FCH-02-9-2020: Fuel cell for prime power in data-centres
Project total cost	EUR 3 576 409.45
Clean H_2 JU max. contribution	EUR 2 499 715.50
Project period	1.1.2021–28.2.2025
Coordinator	Research Institutes of Sweden AB, Sweden
Beneficiaries	Equinix Netherlands BV, InfraPrime GmbH, Snam SpA, SolydEra SpA, TEC4FUELS GmbH, Vertiv, Vertiv Croatia d.o.o.

https://e2p2.eu/

PROJECT AND GENERAL OBJECTIVES

The main objectives of E2P2 are to define the concept of fuel cells for prime power for data centres and create an authoritative open standard for the adaptation of fuel cells to power data centres. E2P2 will demonstrate and validate a proof-of-concept fuel-cell-based prime power module for data centres, and evaluate the opportunities for improved energy efficiency and waste heat recovery. The project strongly anticipates opportunities for European fuel cell suppliers to increase the uptake of their fuel cells across multiple markets, with improved energy efficiency and cost-effectiveness.

NON-QUANTITATIVE OBJECTIVES

- Define the concept of fuel cells for prime power for data centres.
- Create an authoritative open standard for adapting fuel cells to power data centres.
- Demonstrate and validate a proof-of-concept fuel-cell-based prime power module for data centres.
- Collect extensive operational data to support the use of fuel cells as a prime power source for data centres.
- Analyse the combined social, environmental and commercial impacts on the European market.
- Evaluate opportunities for improved energy efficiency and waste heat recovery.
- Generate effective market uptake and create a business strategy.

PROGRESS AND MAIN ACHIEVEMENTS

Vertiv, TEC4FUELS, and SolydEra have successfully developed their modules for the E2P2 project, with meticulous attention to detail. Comprehensive drawings and installation plans have been meticulously crafted. The location has been carefully selected as the Equinix ML 5 site outside Milan, Italy. Substantial data have been gathered for the life-cycle assessment, ensuring thorough analysis.

FUTURE STEPS AND PLANS

The subsequent phase involves conducting factory acceptance testing for the modules, followed by their shipment to Milan for installation. Research Institutes of Sweden will facilitate network connectivity to enable seamless data collection. Once all modules are installed, site acceptance testing will be performed. Subsequently, the E2P2 proof of concept will undergo rigorous testing under full operational conditions for 1 year.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
MAWP (2014–2020)	CAPEX	€/kW	3 500–6 500	
	Availability	% of available plant power	97	
	Electrical efficiency	% (LHV)	42–62	
Project's own objectives	Tolerated H_2 content in natural gas	%	0.2	
	Land use / footprint	m^2/kW	0.11	

SO-FREE

SOLID OXIDE FUEL CELL COMBINED HEAT AND POWER: FUTURE-READY ENERGY

Project ID	101006667
PRR 2024	Pillar 4 – H_2 end uses: stationary application
Call topic	FCH-02-4-2020: Flexi-fuel stationary SOFC
Project total cost	EUR 3 045 355.00
Clean H_2 JU max. contribution	EUR 2 739 094.00
Project period	1.1.2021–31.8.2024
Coordinator	Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile, Italy
Beneficiaries	AVL List GmbH, Elcogen Oy, Fraunhofer-Gesellschaft zur Förderung der Angewandten Forschung EV, ICI Caldaie SpA, Instytut Energetyki, Kiwa Ltd, Kiwa Nederland BV, Polska Grupa Energetyczna SA, Università degli Studi Guglielmo Marconi

www.so-free.eu

PROJECT AND GENERAL OBJECTIVES

The development and demonstration of a fully future-ready system based on solid oxide fuel cells (SOFCs) for combined heat and power generation allows for an operational window of 0–100 % of H_2 in natural gas, with additions of purified biogas. Furthermore, SO-FREE will endeavour to realise a standardised stack–system interface, allowing the full interchangeability of SOFC stack types within a given SOFC combined heat and power system.

NON-QUANTITATIVE OBJECTIVES

SO-FREE aims to realise a unique, standardised stack module–system interface for flexible system integration. The initial alignment of two stack modules with a single interface has been proposed.

PROGRESS AND MAIN ACHIEVEMENTS

- Those involved in the SO-FREE project have set up two identical test stations for independent stack validation and designed a unique stack module–system interface for flexible system integration.
- Stack validation and mapping were completed in February 2023, and the final design of the system in April 2023.

FUTURE STEPS AND PLANS

- Stacks will be produced and delivered in April 2024.
- System demonstrations are planned for October 2024.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SOA result achieved (by others)	Year in which SOA result was reported
Project's own objectives	Durability of stack	kh	> 30	N/A		30	2020
	CAPEX	€/kW	< 3 000	N/A		10 000	
	Thermal efficiency	% (LHV)	40–55	N/A		30–55	
	Electrical efficiency	% (LHV)	55–60	N/A		35–50	
	Availability	%	> 98	N/A		97	
AWP 2020	Degradation	%	< 1	N/A		0.4 % / kh degradation rate for Elcogen E350 stacks has been measured with a fifty–fifty H_2–N_2 mixture and 100 % natural gas	
	Efficiency of H_2 consumption	%	48	0.53		47	

EMPOWER

EUROPEAN METHANOL POWERED FUEL CELL CHP

Project ID	875081
PRR 2024	Pillar 4 – H_2 end uses: stationary application
Call topic	FCH-02-7-2019: Development of highly efficient and flexible mini CHP fuel cell system based on HTPEMFCs
Project total cost	EUR 1 499 876.25
Clean H_2 JU max. contribution	EUR 1 499 876.25
Project period	1.1.2020–30.11.2023
Coordinator	Teknologian tutkimuskeskus VTT Oy, Finland
Beneficiaries	Blue World Technologies ApS, Catator AB, THT Control Oy, Universidade do Porto

https://cordis.europa.eu/project/id/875081

PROJECT AND GENERAL OBJECTIVES

Empower was a project dedicated to developing a highly efficient and versatile mini combined heat and power (CHP) system based on high-temperature proton-exchange membrane fuel cells (HT-PEMFCs). The primary objective of the project was to design and demonstrate a methanol-fuelled mobile CHP system utilising HT-PEMFC technology for simultaneous heat and electricity generation.

Designed to function as a backup or off-grid solution in both industrial and residential settings, the Empower system aimed to provide utility-grade electricity, with waste heat repurposed for space heating and providing domestic hot water. The overarching goal was to enhance the efficiency of systems, specifically targeting the mini-CHP market, while ensuring cost-competitiveness and a low carbon footprint.

The methanol-fuelled CHP system was developed to replace diesel generators, lowering CO_2 emissions, reducing noise and generating heat. Methanol's liquid form enables cost-effective storage and seamless distribution through existing infrastructure, fostering renewable production and reducing dependence on imported fossil fuels.

NON-QUANTITATIVE OBJECTIVES

- Increase visibility and awareness of renewable methanol potential.
- Arranged an international summer school on hydrogen technologies.
- Developed business analysis for renewable methanol use in CHPs and other applications.
- Supported knowledge exchange and production ramp-up through stakeholder searching and information linkage.
- Introduced concept to produce affordable, secure electricity with low carbon footprint.

PROGRESS AND MAIN ACHIEVEMENTS

- Improving materials for fuel cell stacks and refining their quality control methods;
- Studying the novel concept of aqueous-phase reforming as a technology utilised prior to the reforming of methanol;
- Development of a highly efficient gas-phase reformer;
- Development of a custom-made fuel cell system for demonstration purposes;
- Development of a mobile CHP container, acting as a platform for fuel cell systems;
- Integration and short-term testing of CHP system;
- Conduct of final demonstration activities focusing on stand-alone demonstration of the performance of fuel cell systems in relevant conditions;
- Proving the scalability, cost reduction, low carbon footprint and business potential of the project concept.

FUTURE STEPS AND PLANS

"The project has finished.

Opportunities for further research include:

- Integration of a 5 kW fuel cell system with a heat pump for 20–30 kW heat production;
- Design of a bipolar plate to ensure gasket stability;
- Design of a mechanical endplate and compression system;
- Refinement of gasket material;
- Selection of balance-of-plant components for the fuel cell system;
- Integration of a thermoelectric generator in the fuel cell system;
- Use of a Gaussian process regression unit for reforming methanol.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objectives	Stack electrical efficiency (LHV for reformate gas)	%	55	53.7	
	Degradation of the system	%	0.4	1.06	
	Fuel-processing efficiency	%	85	> 85	✓
MAWP (2014–2020)	CAPEX	€/kWh	5 500	2 600	✓
	System electrical efficiency (LHV for methanol)	%	37–67	38.1	✓

AMON

DEVELOPMENT OF A NEXT GENERATION AMMONIA FC SYSTEM

Project ID	101101521
PRR 2024	Pillar 4 – H_2 end uses: stationary application
Call topic	HORIZON-JTI-CLEANH2-2022-04-02: Ammonia powered fuel cell system focusing on superior efficiency, durable operation and design optimisation
Project total cost	EUR 4 293 653.75
Clean H_2 JU max. contribution	EUR 3 998 028.75
Project period	1.1.2023–31.12.2025
Coordinator	Fondazione Bruno Kessler, Italy
Beneficiaries	Alfa Laval Aalborg AS, Alfa Laval SpA, Alfa Laval Technologies AB, Danmarks Tekniske Universitet, École polytechnique fédérale de Lausanne, European Fuel Cell Forum AG, Fachhochschule Zentralschweiz – Hochschule Luzern, Kiwa Cermet Italia SpA, Kiwa Nederland BV, Sapio Produzione Idrogeno Ossigeno SRL, SolydEra SpA, Teknologian Tutkimuskeskus VTT Oy

https://amon-project.eu/

PROJECT AND GENERAL OBJECTIVES

AMON will develop a novel system for the utilisation of ammonia and conversion of it into electric power with high efficiency using a solid oxide fuel cell system. The project will deal with the design of the basic components of the system, including the fuel cell, an ammonia burner and ammonia-resistant heat exchangers; the engineering of the whole balance of plant; and the validation of compliance with ammonia use of all parts and components. Optionally, depending on system needs, an ammonia cracker and anode gas recirculation system will be developed.

The general objectives of the project are to:

- design and develop a fuel cell stack module at a scale of 8 kWel, tested and certified to convert ammonia into power, possibly using the internal reforming capacity of a solid oxide cell operating at a high temperature and managing the power output through the control of the cell's fuel utilisation;
- certify all the components and related materials of a system as 100 % tolerant to ammonia;
- aim to make the system 70 % electrically efficient;
- certify the system for at least 3 000 hours' operation, demonstrating an ammonia availability of 90 % in the operating hours and a degradation rate less than 3 % with nominal power, measured over 1 000 hours of continuous operation.

NON-QUANTITATIVE OBJECTIVES

- Diversify and secure the energy supply.
- Unlock wide market potential and foster efficient conversion systems to decarbonise hard-to-abate sectors such as the maritime and autonomous power systems sectors, in which volumetric density and long-term storage solutions are key requirements.
- Raise industrial interest in ammonia and foster the development of new markets and new jobs.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?	SOA result achieved (by others)	Year in which SOA result was reported
Project's own objectives	Partial load operation	% of nominal load	Dynamic range of operation for 30–100 % of nominal load		N/A	N/A
	FC system tolerance to ammonia	%	System fed by 100 % ammonia as fuel		N/A	N/A
	Degradation at CI and FU = 75 %	%/1 000 h	≤ 2.5		4	2019
	Efficiency	%	70–65		52.1	2020
	Availability	%	> 90		N/A	N/A
SRIA (2021–2027)	CAPEX 5–50 kWe	€/kW	5 000		N/A	N/A

NB: KPI, key performance indicator.

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SWITCH

SMART WAYS FOR IN-SITU TOTALLY INTEGRATED AND CONTINUOUS MULTISOURCE GENERATION OF HYDROGEN

Project ID	875148
PRR 2024	Pillar 4 – H_2 end uses: stationary application
Call topic	FCH-02-3-2019: Continuous supply of green or low carbon H_2 and CHP via solid oxide cell based polygeneration
Project total cost	EUR 3 746 753.75
Clean H_2 JU max. contribution	EUR 2 992 521.00
Project period	1.1.2020–31.3.2024
Coordinator	Fondazione Bruno Kessler, Italy
Beneficiaries	Deutsches Zentrum für Luft- und Raumfahrt EV, École polytechnique fédérale de Lausanne, HyGear BV, Shell Global Solutions International BV, SolydEra SA, Sweco Polska Sp z.o.o.

https://switch-fch.eu/

PROJECT AND GENERAL OBJECTIVES

The Switch project aims to design, build and test a 25 kW (solid oxide fuel cell (SOFC)) /75 kW (solid oxide electrolyser cell (SOEC)) system prototype for hydrogen production, operating in an industrial environment for 5 000 hours. The Switch system will be a stationary, modular and continuous multisource H_2 production technology designed for H_2 refuelling stations. The core of the system will be a reversible solid oxide cell operating in electrolysis mode (SOEC) and fuel cell mode (SOFC).

NON-QUANTITATIVE OBJECTIVES

- Switch aims to ensure the reliability and stability of power and hydrogen supply. A system with cogeneration potential with substantial dynamic behaviour can deliver reliable and stable production of hydrogen and power to match demand-side management, securing the form of energy needed and connecting the generation profile to the end user.
- The project aims to ensure modularity through the development and validation of two modules, each producing 50 kg of H_2 per day. This will be achieved by integrating modules composed of high-reliability stack modules provided by SolydEra.
- Switch aims to ensure that the hydrogen purity level complies with ISO 14687. Hydrogen will be purified to within the range of 99.70 % to 99.99 %, and will have a water content of less than 5 ppm.
- In-field testing in a relevant environment will be assured, installing the final Switch system prototype in a bench infrastructure and in a real operational environment. The system will be operated for 5 000 hours in the relevant environment.
- A life-cycle analysis and life-cycle cost analysis will help to evaluate the benefits of the Switch technology in comparison with state-of-the-art steam methane reforming and other H_2 production technologies (electrolysis).

PROGRESS AND MAIN ACHIEVEMENTS

École polytechnique fédérale de Lausanne (EPFL) has performed the life-cycle assessment and life-cycle costing on the Switch system (SOEC). The Switch system was compared with competing technologies, including proton exchange membrane, alkaline water electrolyser and anion exchange membrane electrolysis.

The following were considered in the analysis:

- all electrolyser manufacture processes and environmental impact of 1 kW electrolyser unit;
- different types of renewable electricity (wind, solar and hydroelectric power);
- electricity mix of different countries;
- degradation impact (for final outcomes).

Three different hydrogen storage methods have been tested and compared through life-cycle analyses. EPFL conducted life-cycle costing and a sensitivity analysis on the pilot plant's operation and performed various case studies to meet the EUR 5/kgH_2 target.

EPFL reported that the segmented short stack test with daily SOFC/SOEC switching showed no degradation but instead a slight improvement during operation. This was confirmed by local impedance measurement data. The local mapping of current density, voltage and temperature also confirmed that the thermoneutral operating point of 1.3 V provides the most homogeneous regime and is therefore the best target for operation in SOEC mode. Regimes of feed starvation (SOFC or SOEC) were also diagnosed and quantified during this test.

The control system was finalised and the PLC/SPLC was delivered and installed.

New communication materials (factsheets) were designed. This activity was led by Fondazione Bruno Kessler, which also launched a 'factsheet campaign' on social media. The campaign resulted in a large increase in followers on LinkedIn.

In 2023, Switch received the Energy Globe Award (application submitted by Fondazione Bruno Kessler). In addition, Elena Crespi (who conducted research as part of the Switch project) won the Young Scientist Award 2023.

FUTURE STEPS AND PLANS

The prototype will be tested and a final event will be held.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SOA result achieved (by others)	Year in which SOA result was reported
Project's own objectives	Low switching time	minutes	30	15	✓	N/A	N/A
	Fuel cell conversion efficiency	%	75	0.66		80	2021
	Cost of H_2	€/kg	5	N/A		11.2	2020
	Electrolyser conversion efficiency	%	75	78		80	2021
	Stack lifetime	hours	10 000	N/A		3 000	2021

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24/7 ZEN

REVERSIBLE SOEC/SOEFC SYSTEM FOR A ZERO EMISSIONS NETWORK ENERGY SYSTEM

Project ID	101101418
PRR 2024	Pillar 4 – H_2 end uses: stationary application
Call topic	HORIZON-JTI-CLEANH2-2022-04-03: Reversible SOC system development, operation and energy system (grid) integration
Project total cost	EUR 5 499 822.50
Clean H_2 JU max. contribution	EUR 5 499 822.50
Project period	1.2.2023–31.1.2026
Coordinator	Fundació Institut de Recerca en Energia de Catalunya, Spain
Beneficiaries	Bosal Emission Control Systems NV; Cluster Viooikonomias Kai Perivallontos Dytikis Makedonias; Diaxiristis Ethnikou Sistimatos Fisikou Aeriou Anonimi Eteria; Ethniko Kentro Erevnas Kai Technologikis Anaptyxis; Eunice Laboratories Monoprosopi Anonymi Etaireia; Fachhochschule Zentralschweiz – Hochschule Luzern; Idryma Technologias Kai Erevnas; Inerco Ingenieria; Tecnologia y Consultoria SA; Kiwa Cermet Italia SpA; Kiwa Creiven SRL; Ostschweizer Fachhochschule; Politecnico di Torino; SolydEra SA; SolydEra SpA

https://24-7zenproject.eu/

PROJECT AND GENERAL OBJECTIVES

24/7 ZEN aims to design and construct a highly efficient 33/100 kW reversible solid oxide cell (rSOC) power-balancing plant, showcasing its compatibility with both electricity and gas grids. The project consortium, comprising diverse expertise, leads innovation in energy management and rSOC system development.

The consortium pioneers advancements across the value chain, enhancing components from cell-level material to fully operational rSOC systems and plug-and-play grid interconnection ecosystems on the demonstration site. Key players include an organisation involved in renewable energy generation (EUNICE), a transmission system operator (DESFA) and an international quality assurance body (Kiwa). The 24/7 ZEN ecosystem will showcase efficient power-to-gas-to-power routes, utilising H_2 or natural gas as fuel, enabling H_2 grid injection, transitioning in less than 30 minutes and achieving a round-trip efficiency of 45 %, all while adhering to standards and safety regulations.

The consortium aims to develop and validate a scalable ecosystem applicable to multi-MW installations. Further research will focus on improving rSOC performance (targeting degradation rates of 0.4 %/kh for 1 000 hours and a current density of 1.5 A/cm^2 in both modes) and enhancing cost-competitiveness (reducing CAPEX from EUR 6 000 / kW to EUR 3 500 / kW).

The project partners that are well connected in the European hydrogen, electricity and grid services sector will disseminate newly developed business models and practices for renewable energy storage, including innovative approaches to delivering green hydrogen.

Through advancing rSOC technology towards commercial deployment, the project contributes to the realisation of renewable hydrogen deployment necessary for achieving a climate-neutral Europe, presenting viable scenarios for grid balancing and green hydrogen supply through conducting in-depth techno-economic analysis.

NON-QUANTITATIVE OBJECTIVES

- Identify requirements for a 24/7 ZEN ecosystem compatible with and connected to the grid.
- Enhance the performance of the 24/7 ZEN system by optimising rSOC cell and stack manufacturing.
- Design, manufacture and test to validate a complete, scalable rSOC system.
- Demonstrate the functioning of the entire 24/7 ZEN grid balance ecosystem for at least 4 months.
- Set out a roadmap exploiting project results for the scaling up and deployment of grid balance rSOC systems.

PROGRESS AND MAIN ACHIEVEMENTS

- Top-level requirements for rSOC system integration with electricity and gas grids have been defined, identifying three integration configurations.
- Significant advancements have been made in enhancing SOC components, particularly in electrode testing and interconnect development. The use of Co-free oxygen electrodes and new composition of Fe-AU doped fuel electrodes has achieved high current densities in both modes of operation
- rSOC stack and hot BoP design and development has led to the creation of detailed designs and simulations of the innovative stack together with the thermal management components on a single body solution.
- Ongoing activities in system integration and design, including conceptual engineering and detailed design, have been conducted to ensure seamless integration of components.
- System requirements and use cases have been clearly defined, addressing critical aspects such as electricity supply, water flow, and natural gas supply.

These results signify a significant step forward in the development of the rSOC system, bringing the project closer to its goal of creating a high-performing solution for sustainable grid management.

FUTURE STEPS AND PLANS

- Advancing scalability of outcomes.
- Scaling enhanced button cells to larger areas and stack levels.
- Integrating components like rSOC stack and heat exchangers into the module.
- Constructing the final system, including pre-designed balance of plant.
- Validating fully integrated rSOC system for grid balancing in Greek energy grid through a 4-month demonstration test.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?	SOA result achieved (by others)	Year in which SOA result was reported
Project's own objectives	Efficiency in SOFC mode	%	57		0.5	2019
	Transient time (SOFC/SOEC)	minutes	30		N/A	N/A
	Electricity consumption at nominal capacity	kW/kg	38.7		40.3	2023
	Round-trip efficiency	%	45		37.90	2019
	Reversible capacity	%	33		0.25	N/A
	Current density of SOFC/SOEC	A/cm^2	1.5		1.1	2023
	Degradation rate of SOFC/SOEC	%/kh	0.4		1 (SOFC) / 2 (SOEC)	Current density under co-SOEC
	Current density under co-SOEC	A/cm^2	1		N/A	N/A
	Total system power in rSOC	kW	33/100		25/75	N/A
	CAPEX	€/kW	3 500		2 130	N/A
	Efficiency in SOEC mode	%	80		0.81	2021

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CLEANER

CLEAN HEAT AND POWER FROM HYDROGEN

CLEANER
Clean Heat and Power from Hydrogen

Project ID	101137799
PRR 2024	Pillar 4 – H_2 end uses: stationary application
Call topic	HORIZON-JTI-CLEANH2-2023-04-01: Development and validation of high power and impurity tolerant fuel cell systems ready to run on industrial quality dry hydrogen
Project total cost	EUR 3 949 959.50
Clean H_2 JU max. contribution	EUR 3 949 959.50
Project period	1.1.2024–31.12.2027
Coordinator	SINTEF AS, Norway
Beneficiaries	Albert-Ludwigs-Universität Freiburg, Eurogas, Ferrexpo Services LLC, Fondazione Bruno Kessler, National Gas Transmission plc, PowerCell Sweden AB, Pretexo, Schiphol Nederland BV, Teknologian Tutkimuskeskus VTT Oy, Ukrgasvydobuvannya JSC

http://cleaner-h2project.eu

PROJECT AND GENERAL OBJECTIVES

Hydrogen storage in underground salt cavern structures is very limited; there are three in the United States and one in the United Kingdom. Since the hydrogen mainly originates from steam methane reforming (SMR), the purity is around 95 %. Rock caverns (sealed) are being developed, one of them within the Hybrit project in Sweden, where clean hydrogen from electrolysis will be stored. In most geological storage areas and pipelines, hydrogen will be already, or become, contaminated with substances not suitable for use in all types of fuel cells (e.g. N_2, CO, CO_2, hydrocarbons and sulphur compounds). Hydrogen produced through electrolysis is considered clean; the only impurities are oxygen and water. However, other sources of hydrogen, such as natural gas reforming, have impurities remaining from the production process.

While repurification of this H_2 can and should be done for some applications, for example by pressure swing adsorption, it adds cost and complexity, and is not in all use cases economically feasible. Currently, there is no standard for the quality of H_2 coming from geological storage or pipelines, and knowledge of which contaminants are present in hydrogen from these storage sites is extremely limited.

Large-scale stationary fuel cells in the MW range should be able to operate on such industrial-quality H_2 without repurification. They can offer a low-cost clean alternative both for large-scale (peak) power and heat production and for small, medium and large-scale back-up power units for the critical infrastructure, thereby also improving the resilience of the energy system. The H_2 quality standard under development is expected to become around 98 %, with CO and sulphur compounds the main relevant poisoning impurities, in addition to inert gases such as CO_2 and N_2, so the fuel cell systems must tolerate these.

Cleaner will develop:

- lower-cost and impurity-tolerant catalyst materials, mitigating operating strategies to avoid the impact of potential impurities, and evaluation of new fluorine-free membranes;
- a stationary proton-exchange membrane fuel cell system > 100 kW capable of operating with industrial-quality hydrogen.

NON-QUANTITATIVE OBJECTIVES

Ensure economically and environmentally sustainable development of materials, components and system.

FUTURE STEPS AND PLANS

In the first 7 months of the project, Cleaner will perform a hydrogen impurity survey, mapping the potential impurities expected in the hydrogen value chain. This will serve as a basis for the first material development and testing. Preparations are ongoing on the fuel cell system by PowerCell and at the test facilities of VTT. Tests are planned to start during summer 2025.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?	SOA result achieved (by others)	Year in which SOA result was reported
SRIA (2021–2027)	O & M costs	€ct/kWh	< 1.7		5	2020
	Electrical efficiency	% LHV	52		50	
	Degradation at CI	%/1 000 h	< 0.2		0.4	
	Non-recoverable CRM as catalyst	mg/Wel	< 0.05 gr/kWe for Pt-based catalysts < 0.025 gr/kWe for IrRu single-site catalysts at the anode. Assumptions: Pt catalysts: anode 0.1 mg(Pt)/cm², cathode 0.4 mg(Pt)/cm², Pt recovery rate > 90 % and nr-PGM in the project < 0.05 mg/cm² (i.e. at 1)		0.1	
	Warm start time	seconds	< 15		60	
	CAPEX	€/kW	< 1 000		1 900	
	Availability	%	> 98		98	

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REMOTE

REMOTE AREA ENERGY SUPPLY WITH MULTIPLE OPTIONS FOR INTEGRATED HYDROGEN-BASED TECHNOLOGIES

Project ID	779541
PRR 2024	Pillar 4 – H_2 end uses: stationary application
Call topic	FCH-02-12-2017: Demonstration of fuel cell-based energy storage solutions for isolated micro-grid or off-grid remote areas
Project total cost	EUR 6 740 031.40
Clean H_2 JU max. contribution	EUR 4 995 950.25
Project period	1.1.2018–30.6.2023
Coordinator	Politecnico di Torino, Italy
Beneficiaries	Ballard Power Systems Europe AS, Enel Green Power SpA, Engie EPS Italia SRL, Ethniko Kentro Erevnas Kai Technologikis Anaptyxis, Grupo Capisa Gestión y Servicios SL, Hydrogenics Europe NV, Instituto Tecnológico de Canarias SA, Instrumentación y Componentes SA, IRIS SRL, Orizwn Anonymh Techniki Etaireia, PowiDian, SINTEF AS, Stiftelsen SINTEF, TrønderEnergi AS

https://www.remote-euproject.eu/

PROJECT AND GENERAL OBJECTIVES

Remote demonstrated the technical and economic feasibility of H_2-based energy storage solutions (integrated power-to-power (P2P) systems, non-integrated power-to-gas and gas-to-power systems (G2P), customised P2P systems) deployed in three demonstrations, based on renewable energy source (RES) inputs (solar, wind and hydroelectric power) in isolated microgrid or off-grid remote areas. In the 5 years of the project (up to December 2022), the design, procurement, installation, operation and analysis of two demonstrations (in Greece and Norway) have been assessed; the third demonstration (in Spain) was commissioned in 2023.

NON-QUANTITATIVE OBJECTIVES

- Remote aimed to complete the demonstrations' design, installation and operation. The project has generated fundamental knowledge for the next generation of P2Ps based on fuel cells and H_2 technologies adapted to the market and society's needs, making use of scientific advances in the management of off-grid and isolated microgrids.
- The project aimed to build experience throughout the value chain of P2P systems and validate real demonstration units in representative applications of isolated microgrid or off-grid areas. This enabled suppliers, end users and general stakeholders to gain experience for the future deployment of these energy solutions.
- Remote aimed to gather technical data on the operation of H_2-based devices (proton-exchange membrane fuel cells, electrolysers) in long-term real operation in P2P applications. The operation of the P2P systems (lasting more than a year) has generated learning experiences regarding the behaviour of technologies such as fuel cells and electrolysers in P2P applications. Companies now know what to improve.
- The project aimed to complete detailed life-cycle analyses of RES-fed, H_2-based P2P systems in remote locations. The project allows for a detailed understanding of the complete life-cycle analysis achieved by the RES-based P2P systems in remote areas, in terms of metrics such as global greenhouse gas reduction thanks to the adoption of H_2 power in a local RES seasonal storage system.

PROGRESS AND MAIN ACHIEVEMENTS

- Remote has operated a demonstration for 1 year in Norway.
- The running and full analysis of the demonstration in Norway was completed. A technical analysis of the demonstration experience in terms of performance and lessons learned was conducted.
- It has operated a demonstration for 2.5 years in Greece.
- The running and full analysis of the demonstration in Greece was completed. The technical analysis of data collected was finalised.
- The project has also involved the design, commissioning and operation of H_2-based P2P plants.
- Remote finalised the installation and running of the new demonstration in Spain.
- Complete techno-economic analysis of the demonstration experience has been performed with real data, to develop an understanding of how to optimise P2P plants in the future, with improved efficiency and reduced costs.
- A business analysis of the H_2-based P2P plants for remote locations was developed and presented to the market stakeholders.

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 (by others)	Year in which SOA result was reported
MAWP (2014–2020)	Rated efficiency of electrolyser (alkaline)	kWh/kg	50 (2020); 49 (2024)	55–60		55–60	2020
	Rated efficiency of electrolyser (PEM)	kWh/kg	55 (2020); 52 (2024)	50	✓	50	2020
	Electrolyser footprint (PEM)	m^2/MW	100 (2020); 80 (2024)	273		10	2018–2020
	Rated efficiency of fuel cell (PEM)	% (LHV)	42–62 (2024)	45–55	✓	51	2018

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RORE POWER

ROBUST AND REMOTE POWER SUPPLY

Project ID	**824953**
PRR 2024	**Pillar 4 – H_2 end uses: stationary application**
Call topic	**FCH-02-3-2018: Robust, efficient long term remote power supply**
Project total cost	**EUR 4 220 093.75**
Clean H_2 JU max. contribution	**EUR 2 999 190.26**
Project period	**1.1.2019–31.12.2023**
Coordinator	**Teknologian tutkimuskeskus VTT Oy, Finland**
Beneficiaries	**3E Energy Oy, European Fuel Cell Forum AG, SolydEra SpA, Sunfire Fuel Cells GmbH, Sunfire GmbH**

https://rorepower.com/

PROJECT AND GENERAL OBJECTIVES

Fuel cells can play a major role in the energy market as a clean, highly efficient way to produce energy in decentralised power generation. Reliable fuel cell systems for continuous, off-grid energy supply provide very promising export markets for the European fuel cell industry. The applications of this kind of fuel cell technology are characterised by key requirements such as low maintenance, the long service life of components, the possibility of remote monitoring, and reliable operation in critical applications such as oil, gas or safety infrastructure. In addition, they are able to cope with harsh climate conditions in both cold and hot regions. The overall objective of this project is to further develop and demonstrate solid oxide fuel cell systems for off-grid power generation in markets, such as the gas and oil infrastructure in remote regions with harsh climate conditions (from − 40 to + 50 °C), and the supply of power to telecommunication towers, especially in emerging countries (e.g. telecommunication base stations or microwave transceivers). In addition, one objective was to demonstrate the functioning of 47 solid oxide fuel cell (SOFC) units in remote sites.

The project developed and demonstrated the reliable operation of two off-grid, remote power systems from three manufacturers. The requirements of the generators were:

- start-up and operation at − 40°C to + 50 °C ambient temperature for natural gas;
- high electrical efficiency (> 35 %);
- long-term validation and demonstration in a relevant environment to gain reliable data from the field (> 24 months);
- high availability (98.5 %);
- defined service and maintenance concept (maintenance frequency of 15 months);
- fulfilment of the regionally different normative requirements with a modular design;
- increase in the reproducibility of production stages of fuel cell systems in large quantities (> 90 %);
- training course for less-educated personnel (two courses from each manufacturer);
- service contract concept for the end customer (one concept per manufacturer).

NON-QUANTITATIVE OBJECTIVES

The other objectives were:

- application of a standard remote communication/monitoring solution;
- meeting of the regionally different normative requirements with a modular design.

PROGRESS AND MAIN ACHIEVEMENTS

Fifty SOFC remote units have been installed and demonstrated in end user sites, and those units have achieved almost all project targets. This indicates that progress in the project has been good. In comparison with the state-of-the-art achievements, a significant reduction in the total cost of ownership has been achieved by reducing the cost of the balance-of-plant component, and the stack and its periphery. In addition, the common supply chain and joint procurement for the system manufacturer in the case of the generic component and spare parts have reduced the total cost of ownership by a remarkable amount. Furthermore, harmful emissions (CO_2, SOx, NOx, particulate matter), noise, vibrations and the risk of soil contamination by liquid fuels have been reduced and higher power supply security has been reached. Moreover, systems have operated in harsh conditions: Sunfire fuel cells have operated at − 40 °C with natural gas and at − 40 °C with propane; SolydEra has operated at 15 °C with natural gas. All systems have good electrical efficiency, high availability and reasonable maintenance frequency.

FUTURE STEPS AND PLANS

The project has finished.

Original equipment manufacturers are continuing to commercialise their remote SOFC systems: they sell and service fuel cell devices for off-grid energy supply. The most interesting market is the telecommunication sector. However, other markets and applications are also being considered.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
AWP 2018	Temperature of operation in harsh conditions	°C	− 40	− 40 can be achieved with project solutions	✓
	Temperature of system start-up in harsh conditions	°C	− 40 with natural gas and − 15 with LPG	Sunfire has achieved − 40 for start-up with natural gas and LPG. SolydEra has achieved − 15 with natural gas but has not verified a temperature with LPG because there are no units in cold areas	
	Long-term desulphurisation	months	15	15	
	Electrical efficiency	%	> 35	> 35	
	Maintenance frequency	months	15	12	⚙

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EVERYWH2ERE

MAKING HYDROGEN AFFORDABLE TO SUSTAINABLY OPERATE EVERYWHERE IN EUROPEAN CITIES

Project ID	779606
PRR 2024	Pillar 4 – H_2 end uses: stationary application
Call topic	FCH-02-10-2017: Transportable FC gensets for temporary power supply in urban applications
Project total cost	EUR 6 770 248.74
Clean H_2 JU max. contribution	EUR 4 999 945.76
Project period	1.2.2018– 31.12.2023
Coordinator	RINA Consulting SpA, Italy
Beneficiaries	Acciona Construccion SA, Delta1 gGmbH, FRIEM SpA, Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón, Genport SRL, ICLEI Europasekretariat GmbH, Iren Energia SpA, Iren Smart Solutions SpA, Iren SpA, Linde Gas Italia SRL, Mahytec SARL, Parco Scientifico Tecnologico per l'Ambiente SpA, PowerCell Sweden AB, Teknologian Tutkimuskeskus VTT Oy, THT Control Oy

https://www.everywh2ere.eu/

PROJECT AND GENERAL OBJECTIVES

The EVERYWH2ERE project integrated the previously demonstrated robust proton-exchange membrane fuel cell stacks and the low-weight, intrinsically safe pressurised-hydrogen technologies into easy-to-install, easy-to-transport, fuel-cell-based transportable gensets. Six fuel cell – plug and play – gensets fitted in containers were produced and tested through a pan-European demonstration campaign in a demonstration-to-market approach. The prototypes were tested at construction sites, music festivals and urban public events all around Europe, demonstrating their flexibility and their increased lifetimes.

NON-QUANTITATIVE OBJECTIVES

EVERYWH2ERE aimed to support the development of a regulatory framework for transportable hydrogen-fuelled systems.

PROGRESS AND MAIN ACHIEVEMENTS

EVERYWH2ERE was a 71-month project. The project ended after having demonstrated fuel-cell-based gensets of 25 kW and 100 kW.

Despite the COVID-19 crisis, the project achieved its objectives.

In particular, the activities related to the achievement of the project's main objective were:

- realisation and validation of three batches of fuel-cell-based gensets of 25 kW and 100 kW;
- implementation of the San Sebastian demonstration in Spain targeting construction sites, the Tenerife demonstration in Spain targeting the cold ironing sector and several demonstrations at events across Europe;
- investigation of the regulatory framework and declaration of conformity for the 100 kW genset;
- development and testing of a second and third batch of gensets;
- engagement of stakeholders in demonstrations in ports, at music festivals, in cities, etc.;
- conduct of the first life-cycle assessment of the EVERYWH2ERE gensets compared with traditional diesel-fuelled gensets;
- mapping of hydrogen supply points in the EU and conduct of a preliminary analysis of logistic aspects;
- definition of contractual models to be proposed to engaged demonstration sites and identification of short-term rental as the most relevant market for EVERYWH2ERE gensets;
- determination of potential business models;
- drafting of EVERYWH2ERE's gensets replication strategy;
- running of a robust dissemination campaign to engage the organisers of music festivals and other events, as well as cities, in the project;
- identification of the film industry as another sector in which EVERYWH2ERE's gensets could be demonstrated;
- identification of the project's key exploitable results and analysis of partners' exploitation intentions and of the intellectual property rights framework.

Effective and appropriate project communication was performed through the project's website, social media, flyers and posters, and dedicated events. A strong effort was made to reach the maximum number of key players in the relevant industries, potential end users and members of the general public who were interested in EVERYWH2ERE solutions. Such efforts resulted in the EVERYWH2ERE consortium being acknowledged through three relevant Fuel Cells and Hydrogen Joint Undertaking (FCH JU) awards:

- FCH JU Best Outreach Award 2020;
- FCH JU Best Innovation Award 2021;
- Atlantic Project Award 2023.

FUTURE STEPS AND PLANS

The project has finished."

External stakeholders showed interest in the future replication of EVERYWH2ERE gensets in additional demonstration activities at public events (FERCAM-run events in Italy and Expo 2025 in Japan) and offshore (at the Oceanic Platform of the Canary Islands in Spain). In addition, a non-binding letter of intent in which RINA Consulting, Parco Scientifico Tecnologico per l'Ambiente SpA, Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón, Genport and PowerCell Sweden commit to following up with the activities related to the EVERYWH2ERE project prototypes is in the process of being signed. This letter sets out the interests of the partners in keeping the prototypes and considers them free to operate them and demonstrate their functionality or to move them to other locations for further research or demonstrations.

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PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objectives	CO_2eq emission savings compared with grid supply	kgCO_2eq	–	242 (Acciona); 75.6 (Motorland); 24.9 (port of Tenerife)	⚙
	Project website visits	number	–	< 1 000	
	Contractual costs for rental compared with diesel or fossil-fuel-based gensets	%	Around 10	N/A	
	GHG emission savings compared with fossil-fuel-based gensets	kgCO_2eq	–	> 2 500 (Acciona); 230 (Motorland); 75.9 (port of Tenerife)	
	Stack efficiency	%	50	50.2	
	Reduction of manufacturing costs and time	%	– 20	N/A	
	PBT for a construction company purchasing a genset and using it at its construction sites	years	–	N/A	
	Weight	kg	–	8 600	
	Volume	m^3	–	32	
	Number of social media interactions	–	–	1 500	
	FC peak voltage	V	–	270–480	
	LCOE of the genset (identification of replication market with contractual costs ± 10 % of those of current power supply solutions)	€/kWh	1.1	N/A	
	OPEX for maintenance and hydrogen supply	%	– 10	N/A	
	Festivals and events hosting EVERYWH2ERE's H2 Corner	number	3	4	✓
	Cities involved	number	20	> 20	
	Festivals and events hosting EVERYWH2ERE gensets	number	3–6	2 for 25 kW; 5 for 100 kW	
	Future manufacturing CAPEX (of the system)	€/kW	5 500	2 394 for 100 kW genset; 5 500 for 25 kW genset	
	FC peak current	A	–	250–450	
	Stack durability	equivalent operating hours	20 000	20 000	
	Noise emission of the full genset (not only the FC SuSy)	dB	< 65	60	
	Installation time	hours	6	N/A	
	Stakeholder events attended	–	3	19	

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FLEX4H2

FLEXIBILITY FOR HYDROGEN

Project ID	101101427
PRR 2024	Pillar 4 – H_2 end uses: stationary application
Call topic	HORIZON-JTI-CLEANH2-2022-04-04: Dry low NOx combustion of hydrogen-enriched fuels at high-pressure conditions for gas turbine applications
Project total cost	EUR 4 872 197.50
Clean H_2 JU max. contribution	EUR 4 178 517.25
Project period	1.1.2023–31.12.2026
Coordinator	Ansaldo Energia SpA, Italy
Beneficiaries	Ansaldo Energia Switzerland AG, Arttic Innovation GmbH, Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique, Deutsches Zentrum für Luft- und Raumfahrt EV, Edison SpA, European Turbine Network, SINTEF Energi AS, Zürcher Hochschule für Angewandte Wissenschaften

https://flex4h2.eu/

PROJECT AND GENERAL OBJECTIVES

FLEX4H2 will design, develop and validate a highly fuel-flexible sequential combustion system capable of operating with any concentration of hydrogen admixed with natural gas up to 100 % at H-class operating temperatures, with the aim of maintaining rated power and efficiency. FLEX4H2 will tackle challenges related to H_2 combustion by developing combustion technology through a combination of design optimisation, analytical research and validation in a relevant environment.

FLEX4H2 will validate scaled and full-size prototypes of the combustor through dedicated atmospheric and high-pressure tests campaigns up to technology readiness level 6. The tests will seek to demonstrate the combustor's ability to operate in the presence of any mixture of hydrogen and natural gas without diluents and while complying with emission limits. In addition, the possibility of starting up an engine with any amount of H_2 in natural gas will be demonstrated.

NON-QUANTITATIVE OBJECTIVES

FLEX4H2 will assess the replicability of the scientific methodologies applied and the transferability of the results to different gas turbine classes.

PROGRESS AND MAIN ACHIEVEMENTS

H2-Optimised Prototypes Design and Testing:

- First generation of H2-optimised prototypes successfully designed and tested.
- Testing activities were completed according to the project plan, demonstrating all target results.
- Further testing with H2 up to 100% was conducted, demonstrating the combustor's fuel and operational flexibility.

Numerical Modelling:

- Platform for exchange of burner geometry/data between CERFACS-ANSALDO has been established.
- First DLR validation case has been selected for 2nd combustion stage, rig geometry has been transferred.
- Initial testing on commercially-relevant CBB configuration has been conducted.

Thermoacoustics:

- Experimental rig geometry has been finalized through network modelling tool.
- Thermoacoustic measurements in Full Can Setup has been carried out.

FUTURE STEPS AND PLANS

Combustion System Development and Testing:

- Focus on second generation H2-optimised prototypes development and validation.
- Utilize data from first development cycle for refinement of burner design.
- Use fullscale atmospheric and high-pressure combustion tests to enhance combustor operation.
- Optimize hardware design considering cooling and mechanical integrity requirements for reproducing full-engine boundary conditions.

Numerical Modelling:

- Perform large eddy simulation on both combustion stages.
- Refine model in first stage (MBFS) to represent burner flashback behaviour and flame stabilisation.
- Enhance modelling activities for thermo-acoustic assessment and modelling.
- Improve second-generation geometry, focusing on aerodynamic improvement of the mixing section.

Thermoacoustics:

- Convert experimental rig geometry to a network modelling tool to reduce model and measurements deviation.
- Expand first-stage-only network model to FCS to prove first-stage-only behavior from experimental data.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
SRIA (2021–2027)	NOx emissions	ppmv at 15 % O_2 (dry)	< 25 by 2024 and < 25 by 2027	
		mg / MJ fuel	< 29 by 2024 and < 24 by 2027	
	Range of H_2 content in gas turbine fuel	%mass	0–100	
		%vol.	0–100	
	Maximum H_2 content of fuel during start-up	%mass	0–100	
		%vol.	0–100	
	Ability to handle H_2 content fluctuations	%mass/min	± 5.11	
		%vol./min	± 15 by 2024 and ± 30 by 2030	
	Minimum ramp rate	%load/min	10 at 100 % H_2	
	Maximum reduction in efficiency of H_2 operation	percentage points	< 2 at 100 % H_2	

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HELIOS

STABLE HIGH HYDROGEN LOW NOX COMBUSTION IN FULL SCALE GAS TURBINE COMBUSTOR AT HIGH FIRING TEMPERATURES

Project ID	101101462
PRR 2024	Pillar 4 – H_2 end uses: stationary application
Call topic	HORIZON-JTI-CLEANH2-2022-04-04: Dry low NOx combustion of hydrogen-enriched fuels at high-pressure conditions for gas turbine applications
Project total cost	EUR 3 984 187.50
Clean H_2 JU max. contribution	EUR 3 984 187.00
Project period	1.3.2023–28.2.2027
Coordinator	Technische Universiteit Eindhoven, Netherlands
Beneficiaries	Centro di Combustione Ambiente SpA, Deutsches Zentrum für Luft- und Raumfahrt EV, OPRA Engineering Solutions BV, OPRA Turbines International BV, Technische Universiteit Delft, Thomassen Energy BV

https://www.h2gt-helios.eu/

PROJECT AND GENERAL OBJECTIVES

In addition to its technical advancements, Helios will play a crucial role in fostering a vast innovative ecosystem and facilitating the future adoption and commercialisation of this technology on a cost-effective and scalable basis. As Europe transitions towards renewable energy sources, the repurposing of existing power generation assets to decarbonised alternatives becomes essential. Gas turbines, providing grid inertia and stability along with dispatchable firming capacity, are pivotal in balancing the inherently intermittent renewable energy sources. The Helios project addresses these challenges, contributing significantly to securing, competitively pricing, cleaning, flexibly managing and resiliently shaping Europe's energy system.

The Helios consortium, comprising five partners across three European countries is highly complementary.

Helios aims to achieve the following objectives:

- enable low-NOx combustion of hydrogen-enriched fuels in gas turbines;
- operate the system across a wide range of mixtures, from 100 % natural gas to 100 % hydrogen;
- achieve low NOx emissions (below 9 ppmv);
- modify existing combustors to safely operate at high firing temperatures using 100 % H_2, based on Thomassen Energy's FlameSheet technology;
- provide the combustor as either a newly built option or a retrofit for existing gas turbine systems ranging from 1 MW to 500 MW;
- make the combustor applicable to various industrial and heavy systems, as well as industrial-scale gas turbines.

NON-QUANTITATIVE OBJECTIVES

The Helios project aims to advance the scientific understanding and feasibility of hydrogen-enriched fuels in gas turbines, utilising the FlameSheet combustor framework. Economically, it strengthens European industrial technology by enhancing hydrogen-enriched gas-turbine technology and testing facilities, promoting Europe's leadership position and generating new industrial activities. Financially, it accelerates sustainable energy generation by retrofitting existing gas turbines, minimising social impact and ensuring job security. Environmentally, Helios addresses societal acceptance through socioeconomic evaluation and stakeholder involvement. Overall, Helios improves EU energy security by widening gas turbine operation capabilities, ensuring grid stability and enhancing supply reliability.

PROGRESS AND MAIN ACHIEVEMENTS

Preliminary data from a high-pressure campaign indicated good results. They showed improvements in firing temperatures, particularly with 100 % hydrogen. Preliminary data indicated promising results in terms of flashback resistance. As data are preliminary, it is essential to double-check and verify the findings.

FUTURE STEPS AND PLANS

Helios has been running now for more than 1 year. At the end of the project, we shall deliver a handbook of requirements and recommendations for the implementation of high-hydrogen gas turbines, as one of the key outcomes.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?	SOA result achieved (by others)	Year in which SOA result was reported
Project's own objectives and SRIA (2021–2027)	NOx emissions	ppmv at 15 % O_2 (dry)	< 9		< 25	2020
		mg / MJ fuel	8.7		31	
	Range of H_2 content in gas turbine fuel	%mass	0–100		0–5	
		%vol.	0–100		0–30	
	Ability to handle H_2 content fluctuations	%mass/min	2.21		1.4	
		%vol./min	15		10	
	Reduction in maximum efficiency in H_2 fuel cell operation	percentage points	< 10 at 100 % H_2		10 at 30 % H_2	
	Minimum ramp rate	%load /min	15 at 100 % H_2		10 at 30 % H_2	
	Maximum H_2 content of fuel during start-up	%mass	100		0.7	
		%vol.	100		5	

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ACHIEVE

ADVANCING THE COMBUSTION OF HYDROGEN–AMMONIA BLENDS FOR IMPROVED EMISSIONS AND STABILITY

Project ID	101137955
PRR 2024	Pillar 4 – H_2 end uses: stationary application
Call topic	HORIZON-JTI-CLEANH2-2023-04-02: Research on fundamental combustion physics, flame velocity and structure, pathways of emissions formation for hydrogen and variable blends of hydrogen, including ammonia
Project total cost	EUR 2 994 200.00
Clean H_2 JU max. contribution	EUR 2 994 200.00
Project period	1..1.2024–30.6.2027
Coordinator	Sapienza Università di Roma, Italy
Beneficiaries	CentraleSupelec, Centre national de la recherche scientifique, King Abdullah University of Science and Technology, Phoenix Biopower AB, Phoenix Biopower Switzerland GmbH, State Enterprise Zorya Mashproekt Gas Turbine Research and Production Complex, Technische Universität Berlin, Technische Universiteit Delft, Università degli Studi di Firenze, Zabala Innovation Consulting SA

https://cordis.europa.eu/project/id/101137955

PROJECT AND GENERAL OBJECTIVES

The main objective of Achieve is to enable the reduction of pollutant gases (CO_2 and NOx) from current and future gas turbine installations by providing a broad knowledge base and set of validated (technology readiness level 4) solutions for the combustion of unconventional H_2 blends in gas turbines – that is, with combinations of H_2, NH_3, CH_4, N_2 and H_2O. Focused dissemination of and efforts to exploit results within the research and industry communities will allow those conducting the project to build on these results to (i) develop technology and solutions for current gas turbine engines equipped with conventional swirl-stabilised dry low emission combustion systems; and (ii) develop novel combustor systems for future gas turbines with significantly lower emissions and better operability than current engines over a wider range of unconventional H_2 blends.

H_2 is envisaged by many as the main substitute for natural gas in the short/medium term when produced from renewable or low-carbon energy sources, particularly when these are in excess. However, there are several challenges with the combustion of H_2, which include higher chances of static (flashback) and dynamic (thermoacoustic) instabilities, and the strong sensitivity of hydrogen flames to pressure. Critically, there are also significant challenges related to the storage and transport of hydrogen due to its high reactivity and low energy density, making widespread implementation economically and technically difficult.

NH_3 can act as a carbon-free carrier of hydrogen. NH_3 flame speeds are much lower than those of hydrogen, and the infrastructure and knowledge required to produce, transport and store large quantities of ammonia are already established, as NH_3 is used extensively in fertilisers. However, NH_3 has a low burning velocity, has a narrow flammability limit, can produce a very high level of NOx and can be toxic, limiting its use in practical combustion applications. Blends of ammonia and hydrogen have been studied as means to combine the benefits of both fuels while mitigating their limitations. These blends can be tailored to have more favourable combustion characteristics, for example flame speeds, flammability limits and NOx emissions, than pure NH_3, and better safety than pure H_2 flames.

One promising pathway is to utilise NH_3 for the transport and storage of renewable energy. Others are the (partial) local conversion of NH_3 into H_2, and the combustion of H_2/NH_3 mixtures for power generation.

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ACHIEVE

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
SRIA (2021–2027)	Ability to handle H_2 content fluctuations	-	For stable operation with H_2 fluctuations, around 30 %vol./min (TUB burner)	
	NOx emissions	-	65 % reduction in NOx in premixed operations; 80 % in non-premixed operations (jet-in-hot-coflow burner)	
	Ability to handle H_2 content fluctuations	%vol./min	Stable combustion of H_2 blends with 20 % NH_3 (TUB burner)	
	Range of H_2 content in gas turbine fuel	%mass	100 in conventional swirl-stabilised and novel burners	
	Ability to handle H_2 content fluctuations	-	Low combustion instabilities (lower than 0.15 % of the operating) for 100 % H_2	
	NOx emissions	ppm	< 100 with up to 20 % NH_3 (TUB burner)	
	Events presenting the project per year and links with other EU projects	number	3	
	Range of H_2 content in gas turbine fuel	%vol.	Up to 20 % NH_3 (TUB burner)	
	Ability to handle H_2 content fluctuations	-	Stable operation with H_2 fluctuations around 30 %vol./min (TUB burner); no instabilities p_RMS/p_op < 0.15 %; no flashback; no lean blowout, with a real-time monitoring system to achieve stable operation	
	Peer-reviewed papers published	number	12	
	Range of H_2 content in gas turbine fuel	%vol.	Validation of models to within 5 % accuracy (KPI 2.1)	
	NOx emissions	ppmv at 15 % O_2 (dry)	Validation of models to within 10 % accuracy	
	Ability to handle H_2 content fluctuations	%mass/min	Stable combustion with 100 % H_2 (TUB burner)	
	Validated computational singular perturbation skeletal-mechanism- and virtual-chemistry-mechanism-derived mechanisms for a use case	-	28 % thermal cracking of NH_3 yielding 32.8 % H_2, 10.9 % N_2 and 56.3 % NH_3 by volume	
	NOx emissions	mg/MJ fuel	< 25 ppm with 100 % H_2 (TUB burner)	

H2AL

FULL-SCALE DEMONSTRATION OF REPLICABLE TECHNOLOGIES FOR HYDROGEN COMBUSTION IN HARD TO ABATE INDUSTRIES: THE ALUMINIUM USE-CASE

Project ID	101137610
PRR 2024	Pillar 4 – H_2 end uses: stationary application
Call topic	HORIZON-JTI-CLEANH2-2023-04-04: Hydrogen for heat production for hard-to-abate industries (e.g. retrofitted burners, furnaces)
Project total cost	EUR 7 005 639.25
Clean H_2 JU max. contribution	EUR 5 993 812.38
Project period	1.1.2024–31.12.2026
Coordinator	Université libre de Bruxelles, Belgium
Beneficiaries	2A SpA, Bluenergy Revolution SCARL, EKW GmbH, European Aluminium, Fraunhofer-Gesellschaft zur Förderung der Angewandten Forschung EV, Fundacion Tecnalia Research & Innovation, Gas- und Wärme-Institut Essen EV, GHI Hornos Industriales SL, Nippon Gases Industrial SRL

https://cordis.europa.eu/project/id/101137610

PROJECT AND GENERAL OBJECTIVES

The overall objective of the H2AL project is to develop, validate, implement and demonstrate at full scale in real operational conditions a set of technologies, such as an integrated hydrogen burner and support systems, refractory materials and sensors, within heating furnaces in hard-to-abate industries – aluminium ingot and internal scrap recycling – by retrofitting an existing furnace at the demonstration site (2A facilities). The demonstration will run for more than 6 months – with at least one trial of 100 hours at 100 % H_2 and with a thermal output of at least 2 MWth – ensuring that technology readiness level 7 is achieved at the end of the project. The impact of H_2 combustion on the refractory materials, overall furnace structure and product quality (aluminium) will also be investigated, and measures to minimise its effects will be implemented. H2AL will also develop and implement a set of data, documentation and guidelines ensuring that the project outcomes can be replicated in other industrial sites (in other hard-to-abate industries) in a cost-effective, sustainable and safe way.

NON-QUANTITATIVE OBJECTIVES

- Understanding hydrogen combustion and its effects.
- Developing safe and efficient H_2 combustion systems for industrial plants.
- Providing insights into the physics of H_2 combustion and its impact on process parameters, using laboratory-scale experiments and simulations.
- Developing a burner for 100 % H_2 and H_2 / natural gas mixtures.
- Redesigning two state-of-the-art oxy-fuel burner technologies to use 100 % H_2 and H_2 / natural gas blends without compromising on aluminium quality, process efficiency or NOx emissions.
- Operating under non-conventional conditions to deliver high efficiency, excellent heat transfer characteristics and low NOx emissions.
- Retrofitting a furnace with the developed burner, optimal refractory materials and sensing solutions.
- Retrofitting 2A's furnace with newly developed oxy-fuel burners, optimised refractory materials and sensors for monitoring the H_2 combustion process.
- Carrying out a full-scale demonstration of H2AL technologies in the aluminium industry.
- Demonstrating the effectiveness and feasibility of H2AL's technologies in the aluminium industry at full scale in 2A facilities.
- Running the demonstration for at least 6 months, operating for at least 100 hours at 100 % H_2.
- Implementing standard operating procedures for safety and plant integration.
- Developing and implementing standard operating procedures to safely integrate H_2 combustion systems in industries that are difficult to decarbonise.
- Shifting conventional industrial processes to hydrogen-based systems.
- Comprehensively evaluating H_2 substitution for fossil fuels in furnaces and other hard-to-abate sectors.
- Investigating potential impacts on process performance, product quality, equipment operation and maintenance.
- Conducting techno-economic analyses to replicate the solution in other industrial sites and industries.
- Studying the impact of H_2 on final product costs and CO_2 emission reduction in final product price under the emissions trading scheme programme.
- Developing and promoting new business models for the widespread exploitation of H_2-based solutions in heat generation in high-tech areas (hard-to-abate industries).
- Developing new business models inspired by traditional industrial energy efficiency energy service company models and energy/gas utility ones.
- Developing a techno-economic tool to assess the economic viability of the proposed solution with different types of H_2 supply.
- Paving the way for the large-scale demonstration of H_2 technologies in burners and furnaces.
- Collaborating with industry stakeholders and regulatory bodies to identify the best approach to adopting these technologies financially sustainably.

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PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives, SRIA (2021–2027) and AWP 2023	Application of H_2 burners with low NOx emissions	mg/Kg	< 100 mg/kg, for example as low as 20 mg/kg for SNCR-enhanced flameless regenerative burners)	
	Enabling the utilisation of H_2-based heat production	-	Enabling the utilisation of H_2-based heat production at the 2A foundry and in other aluminium and hard-to-abate industries	
	Insights into process	-	Insights into the effect of, for example, H_2/O_2 ratio, flame temperature and emissions on process	
	Safety protocol and risk assessment	-	Systematic analysis and application of safety protocol and risk assessment for the use of H_2 at the testing and demonstration site	
SRIA (2021–2027) and AWP 2023	TRL 9 roadmap	-	TRL 9 roadmap for further industry integration, including business model opportunities for replication in other scenarios, including GIS data	
	Comprehensive evaluation of the KPI H_2 combustion	-	Comprehensive evaluation of H_2 combustion	
	Technology roadmap for the effective integration of 100 % H_2 combustion	-	Technology roadmap for the effective integration of 100 % H_2 combustion for heat production in the aluminium industry	
	Roadmap for 100 % elimination of fossil fuel combustion in the aluminium industry	-	Roadmap for 100 % elimination of fossil fuel combustion in the aluminium industry	
Project's own objectives and SRIA (2021–2027)	Technology roadmap and industry best practices	-	Technology roadmap and industry best practices to (at least) maintain the quality of the final product (aluminium) in terms of melt quality, porosity, dimensional accuracy and mechanical properties	
	Full-scale operational demonstration	hours	Full-scale operational demonstration at the 2A foundry, running for at least 100 hours at 100 % H_2	
	Understanding of H_2 utilisation	-	Better understanding of H_2 utilisation	
	Optimised combustion models	-	Optimised combustion models to further improve the consortium's simulation tools for H_2 combustion mechanisms	
	Plant integration processes and procedures	-	Documented demonstrator at 2A facilities, including plant integration processes and procedures	
	New burners	% H_2	New burners capable of using 0–100 % of H_2 / natural gas mixtures	

HYPOWERGT

DEMONSTRATING A HYDROGEN-POWERED GAS-TURBINE ENGINE FUELLED WITH UP TO 100 % H_2

Project ID	101136656
PRR 2024	Pillar 4 – H_2 end uses: stationary application
Call topic	HORIZON-JTI-CLEANH2-2023-04-03: Retrofitting of existing industrial sector natural gas turbomachinery cogeneration systems for hydrogen combustion
Project total cost	EUR 12 269 095.00
Clean H_2 JU max. contribution	EUR 6 000 000.00
Project period	1.1.2024–31.12.2027
Coordinator	SINTEF Energi AS, Norway
Beneficiaries	Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique, Equinor Energy AS, European Turbine Network, Lucart SpA, Nuovo Pignone Tecnologie SRL, SNAM SpA, TotalEnergies OneTech, Zürcher Hochschule für Angewandte Wissenschaften

http://hypowergt.eu

PROJECT AND GENERAL OBJECTIVES

The HyPowerGT project aims to push technological boundaries to enable gas turbines to operate on hydrogen without diluting it. The core technology is a novel dry low-emission combustion technology (DLE H_2) capable of handling mixtures of natural gas and hydrogen with concentrations up to 100 % H_2. The combustion technology was successfully validated at technology readiness level (TRL) 5 (in early 2021), retrofitted on the combustion system of a 13 MWe industrial gas turbine (NovaLT12). Besides ensuring low emissions and high efficiency, the DLE H_2 combustion technology offers fuel flexibility and response capability on a par with modern gas turbine engines fired with natural gas.

The new technology will be fully retrofittable to existing gas turbines, thereby providing opportunities for refurbishing existing assets in industry (combined heat and power) and offering new capacities in the power sector for load-levelling the grid system (unregulated power) and for mechanical drives. The DLE H_2 technology adheres to the strictest specifications for fuel flexibility, NOx emissions, ramp-up rate and safety, as stated in the strategic research and innovation agenda 2021–2027.

The new DLE H_2 combustion technology will be further refined and developed and, towards the end of the project, demonstrated at TRL 7 on a 16.9 MWe gas turbine engine (NovaLT16) fired with fuel blends mixed with hydrogen from 0 % to 100 % H_2. Within this wide range, emphasis is placed on meeting pre-set targets for (i) fuel flexibility and handling capabilities, (ii) concentration of hydrogen fuel during the start-up phase, (iii) ability to operate at varying hydrogen contents, (iv) minimum ramp speed and (v) safety aspects at any level with regard to related systems and applications targeting industrial gas turbine engines in the 10–20 MWe class.

A digital twin will be developed to simulate performance and durability characteristics, emulating the cyclic operations of a real cogeneration plant in the Italian paper industry.

NON-QUANTITATIVE OBJECTIVES

- **To provide a safe and efficient low-emission H_2 combustion system retrofittable to gas turbine engines in the 10–20 MWe class.** The project will provide a novel dry low-emission hydrogen combustion system retrofittable to gas turbines in the 10–20 MWe class, aimed at offering response power to stabilise and increase the reliability of the electrical energy system. Emphasis is placed on the ability to retrofit the existing heat and power generation systems with gas turbines capable of operating with up to 100 % H_2, while guaranteeing high efficiency, low NOx emissions and operational flexibility in line with typical values obtained under conditions similar to those of natural gas combustion, pursuant to the call.
- **To demonstrate the operating capabilities of a simple-cycle gas turbine in full operating conditions with fuel compositions admixed with hydrogen up to 100 % H_2.** The key enabling technology will first be refined and demonstrated in a relevant environment at TRL 6. Then, a demonstration system will be planned, developed and built into an operational environment, and subsequently demonstrated at TRL 7. This endeavour will require at least 60 aggregated fired hours. The following characteristics of the system will be concluded and documented. Emphasis is placed on (i) gas turbine flexibility, (ii) the content of hydrogen fuel during the start-up phase, (iii) the ability of the system to operate at varying hydrogen contents, (iv) minimum ramp speed and (v) an appropriate safety level with regard to related systems and applications.
- **To present pathways for decarbonised power generation through retrofitting and exploiting the project's results.** The project will present credible ways in which its results can best be utilised, both commercially and economically. The work includes assessing the methods used and the transferability of the results to other gas turbine types and brands, and evaluating the market for retrofitting.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives and SRIA (2021–2027)	Fuel flexibility with full operational (load) capability	%vol. H_2	0–100	
		%mass H_2	0–100	
	NOx emissions for 30–100 %vol. H_2	ppmvd at 15 % O_2	< 25	
Project's own objectives	Variability of the rate of H_2 admixing with natural gas	H_2 volume / minute	±30 %	
	Maximum H_2 content during start-up	%mass	100	
		%vol.	100	
	NOx emissions for 0–30 %vol. H_2	ppmvd at 15 % O_2 (dry)	< 15	
		mgw/MJ of heat	< 26	
	Minimum ramp-up rate	% of load / minute	10	
	Efficiency loss in H_2 operations mode	percentage points	< 2	
	Maximum power reduction in H_2 operations mode	%	< 2	
	NOx emissions for 30–100 %vol. H_2	mgw/MJ of heat	< 43	

Clean Hydrogen Partnership

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WASTE2WATTS

UNLOCKING UNUSED BIO-WASTE RESOURCES WITH LOW COST CLEANING AND THERMAL INTEGRATION WITH SOLID OXIDE FUEL CELLS

Project ID	826234
PRR 2024	Pillar 4 – H_2 end uses: stationary application
Call topic	FCH-02-7-2018: Efficient and cost-optimised biogas-based cogeneration by high-temperature fuel cells
Project total cost	EUR 1 681 602.50
Clean H_2 JU max. contribution	EUR 1 681 602.50
Project period	1.1.2019–30.9.2023
Coordinator	École polytechnique fédérale de Lausanne, Switzerland
Beneficiaries	Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile; Arol Energy; Biokomp SRL; Commissariat à l'Énergie Atomique et aux Énergies Alternatives; Etudes et Applications d'Energies Renouvelables et d'Epuration; Paul Scherrer Institut; Politecnico di Torino; SolydEra SA; SolydEra SpA; Sunfire GmbH

https://cordis.europa.eu/project/id/826234

PROJECT AND GENERAL OBJECTIVES

There is a huge amount of biogas available in the agriculture sector in Europe for use by small-scale SOFCs (50 kWe, in theory 0.5 million units or 25 GWe, or 1 500 PJ, equal to 8 % of the EU's natural gas).

WASTE2WATTS aim was to develop cleaning technologies for biogas to make the gas compatible with solid oxide fuel cells (SOFCs). The technology determines what needs to be cleaned from the gas and to what purity level it must be cleaned. It also defines the proper scale for the best application of SOFCs with biogas, and the bioresources available at that scale. It assesses reformer catalysts and cells/stacks with biogas impurities and representative gas mixtures. A system layout proposes operating strategies without external water addition. A 1.5 kWe SOFC running on agro-biogas was prepared, and a novel cryogenic system for cleaning biogas at a scale of 100 m^3/h was installed.

NON-QUANTITATIVE OBJECTIVES

- The project compiled a sorbents database.
- Sorbents' behaviour was analysed in relation to specific contaminants. COS is the most critical contaminant (< 1 g/kg of sorbent).
- If SOFC cells are run with COS, the outlet gases are H_2S and SO_2; the water–gas shift reaction is affected.
- New catalysts for biogas reforming were tested (Ni_4Fe, Ru-doped SmCeCoO). They can cope with poisonings up to 25 ppm for short durations.
- Retention capacity was 0.16 g COS, 3 g DMS, 19 g CH_4S and 223 g H_2S per kilogram of sorbent. Th sorption capacity for non-H_2S compounds was much improved (5 times better) for dry biogas.
- Mixed reformed biogas behaves better than dry reformed biogas; therefore, steam must be added for reforming.

PROGRESS AND MAIN ACHIEVEMENTS

- Sorbents have been characterised specifically for biogas cleaning, allowing for the choice of an adapted cleaning solution (IR).
- Reformer catalysts, cells and stacks characterised with specific sulphur compounds show resilience up to 5 ppm of trace content.
- System cost analysis showed that biogas SOFC can achieve a LCOE of < 15 ct€/kWhe, even at 20 kWe, for a 4-year stack life (stack cost 1 000€/kWe)
- The reformer catalysts can be considered for the Innovation Radar.
- A market evaluation was performed that concluded that >100 000 SOFC units of 50 kWe could be installed in the countries CH, DE, FR, IT unlocking presently unused biogas resource.
- Total testing amounted to >7000h for sorbents, >11 000h for reformer catalysts, 27 000h for cells, >20 000h for stacks, that is,. total on-stream testing of 65 000h mainly by 4 Laboratories during 4 years.
- W2W installed a cryogenic cleaning chain for biogas flow of 100 m^3/g on a real biogas site. It needs further running to test the effectiveness of contaminant removal by this method.
- W2W installed a 1.5 kWe SOFC on an agro-biogas site, which ran for 1 month before being shut down. A new gas-cleaning kit was built and will be deployed on the site, after which the testing will resume for 1–2 years with different sorbents. This will require follow-up financing.
- SolydEra started the production of 10 kWe stacks that can be assembled to offer 50–300 kWe SOFC systems, including to the biogas market. A total of 50 kWe has been identified as a promising market size, in which competition from engines is the lowest.
- The cost calculation for cleaning was refined with results from the field tests.
- Alternative ways of gas cleaning (to form solid sorbents) were investigated.

FUTURE STEPS AND PLANS

The project has finished.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objectives	Pollutant nature and mix	Sulphur compounds	Identification	Critical compounds identified	✓
	Cost of biogas cleaning	€/kWe	< 1 000	< 1 000	
	LCOE	€/kWh	< 15	0.09	
	SOFC degradation on biogas reformate (voltage loss under constant current)	%/kh	0.4	0.2–0.5	
	Pollutant tolerance	ppm	3	3	
MAWP (2014–2020)	SOFC CAPEX	€/kWe	3 500–6 500	2 000–4 000	
	Electrical efficiency	%	35–60	55	

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RUBY

ROBUST AND RELIABLE GENERAL MANAGEMENT TOOL FOR PERFORMANCE AND DURABILITY IMPROVEMENT OF FUEL CELL STATIONARY UNITS

Project ID	875047
PRR 2024	Pillar 4 – H_2 end uses: stationary application
Call topic	FCH-02-8-2019: Enhancement of durability and reliability of stationary PEM and SOFC systems by implementation and integration of advanced diagnostic and control tools
Project total cost	EUR 2 999 715.00
Clean H_2 JU max. contribution	EUR 2 999 715.00
Project period	1.1.2020–31.12.2024
Coordinator	Università degli Studi di Salerno, Italy
Beneficiaries	Ballard Power Systems Europe AS, Bitron SpA, Commissariat à l'Énergie Atomique et aux Énergies Alternatives, Université Bourgogne-Franche-Comté, École polytechnique fédérale de Lausanne, Europäisches Institut für Energieforschung EDF KIT EWIV, Fondazione Bruno Kessler, Institut 'Jožef Stefan', Solidpower SpA, Sunfire Fuel Cells GmbH, Teknologian Tutkimuskeskus VTT Oy, Université de Franche-Comté

https://www.rubyproject.eu/

PROJECT AND GENERAL OBJECTIVES

The RUBY project aims to exploit electrochemical impedance spectroscopy (EIS) for developing, integrating, engineering and testing a comprehensive and generalised monitoring, diagnostic, prognostic and control (MDPC) tool. Thanks to EIS's features, RUBY will improve the efficiency, reliability and durability of solid oxide fuel cells (SOFCs) and polymer electrolyte fuel cell systems for stationary applications. The tool relies on advanced techniques and dedicated hardware, and will be embedded in the fuel cell systems for online validation in relevant operational environments.

NON-QUANTITATIVE OBJECTIVES

The MDPC tool performs monitoring, diagnosis, prognosis control and mitigation of the stack and balance of plant for polymer electrolyte fuel cell systems in back-up applications and for SOFCs for micro combined heat and power applications.

PROGRESS AND MAIN ACHIEVEMENTS

- Tests on polymer electrolyte membrane stacks and systems have been performed in nominal conditions.
- Tests on SOFC stacks have been commissioned.
- Preliminary tests on SOFC systems have been performed in nominal conditions.
- Preliminary versions of monitoring, diagnostics and prognostic algorithms have been developed and tested.
- Hardware (HW) for the MDPC tool has been designed, manufactured and tested.
- The concept and preliminary design of HW for EIS perturbation stimuli have been determined.

FUTURE STEPS AND PLANS

- The project will acquire conventional and advanced signals. The tool measures conventional signals from the balance of plant and stack (voltage, current, temperature, etc.) and the EIS for the stack.
- RUBY will advance the MDPC tool's activities. The tool monitors the state of health of the stacks and the systems, detects faults at the stack and balance-of-plant levels, estimates the stacks' lifetimes, applies advanced control actions and proposes mitigation strategies at the system level.
- Tests will be conducted on the polymer electrolyte membrane stacks and systems in faulty conditions.
- Tests will be performed on SOFC stacks in nominal and faulty conditions.
- Tests will be carried out on the SOFC system in faulty conditions.
- MDPC tool algorithms will be integrated into the HW.
- HW will be commissioned for EIS perturbation stimuli.
- The MDPC tool will be implemented and tested.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SOA result achieved (by others)	Year in which SOA result was reported
Project's own objectives	Lifetime of back-up applications (PEM)	years of operation	15	12		12	2020
	Electrical efficiency of back-up applications (PEM)	% (LHV)	45	45		45	
	Reliability of back-up applications (PEM)	BX–Y	B10–15	B25–12		B25–12	
	Lifetime of micro-CHP applications (SOFC)	years of operation	12	10		10	
	Maintenance costs of back-up applications (PEM)	€/year	452	617		617	
	Availability of micro-CHP applications (SOFC)	%	99	97		97	
	Availability of back-up applications (PEM)	%	99 999	99.99		99.99	
	Electrical efficiency of micro-CHP applications (SOFC)	% (LHV)	39	35		35	
	Stack durability of micro-CHP applications (SOFC)	hours	40 000	30 000		30 000	

Clean Hydrogen Partnership
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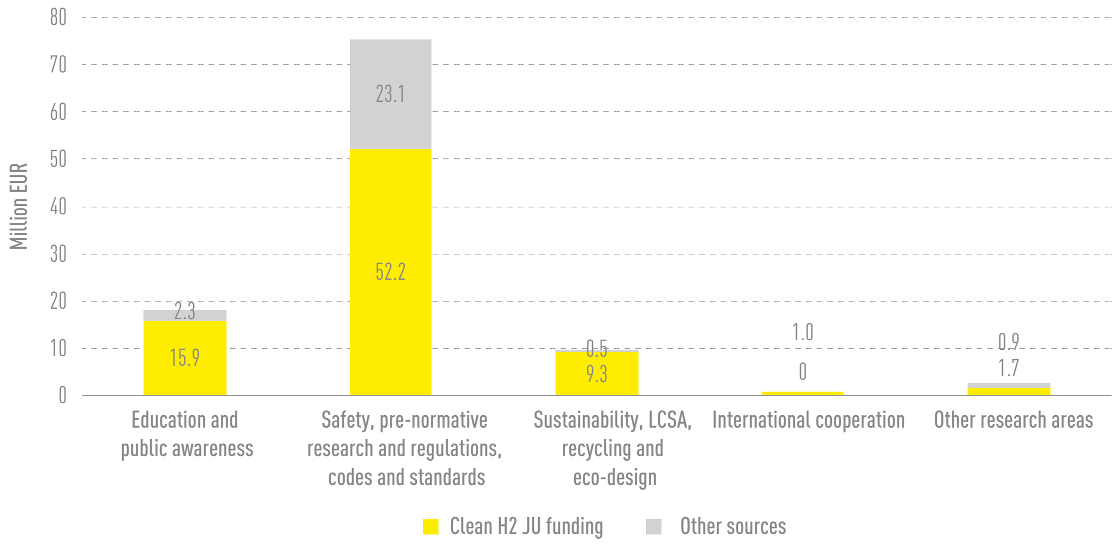
V. PILLAR 5 – CROSS-CUTTING ISSUES

OBJECTIVES: The cross-cutting activities are structured around three broad research fields with the following overarching objectives.

- **Sustainability, LCSA, recycling and eco-design** objectives:
  – develop LCA tools addressing the three dimensions of sustainable development: economic, social and environmental;
  – develop eco-design guidelines and eco-efficient processes;
  – develop enhanced recovery processes (recycling) for CRMs, particularly elements belonging to the platinum group, and for environmentally problematic substances such as PFASs.
- **Education and public awareness** objectives:
  – develop educational and training material and build training programmes on hydrogen and FCs for professionals and students;
  – raise public awareness and trust of hydrogen technologies and their benefits.
- **Safety, pre-normative research (PNR) and regulations, codes and standards (RCS)** objectives:
  – increase the level of safety of hydrogen technologies and applications;
  – support the development of RCS for hydrogen technologies and applications, with a focus on standards.

OPERATIONAL BUDGET: Between 2008 and 2023, the JU supported 54 projects relevant to this pillar with a total contribution of EUR 80.1 million, complemented by EUR 26.8 million worth of other contributions. This corresponds to approximately 5 % of the total cumulative budget. The distribution of total historical pillar 5 budgets among research areas is shown in Figure 28.

Figure 41: Funding for pillar 5 projects from 2008 to date

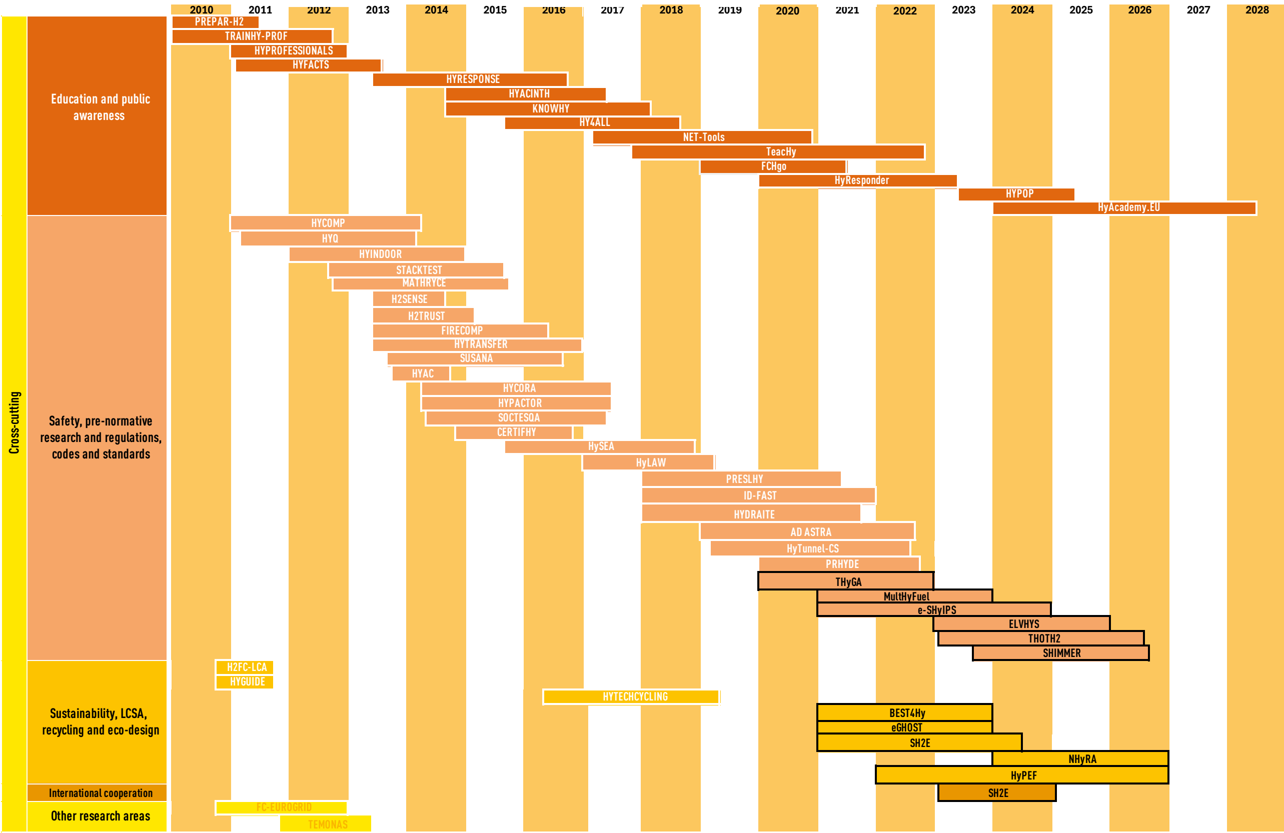


Source: Clean Hydrogen JU.

PROJECTS IN BRIEF:

The 2024 programme technical assessment covers 15 projects, those in black font in Figure 28.

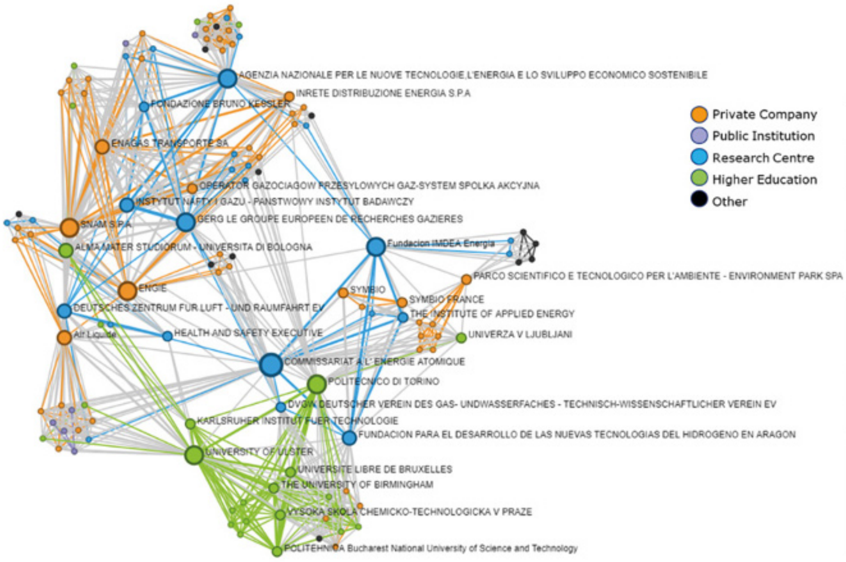
Figure 42: Project timelines for pillar 5 – cross-cutting topics



Source: Clean H2 JU, 2024.

Figure 43 shows the connections between partners present in the projects in the cross-cutting pillar. In past years, the public research and academic centres used to represent the majority of the project partners in the cross-cutting activities, with one centre involved in many of the projects. This has always been a characteristic of this Pillar, due in particular to the education and sustainability dimensions, but also to some projects dedicated to public safety, focussing on fundamental rather than applied knowledge, and therefore relying more on academic competences. This picture has started to change, probably triggered by an increase of interest in the topics of Pillar 5 by private companies. In 2023, two private companies had an important role, this year three appear among the top participants.

Figure 43: TIM plot showing the participants in the 15 projects assessed in pillar 5



Top Participants

Participant	Number of Projects
COMMISSARIAT A L' ENERGIE ATOMIQUE	5
UNIVERSITY OF ULSTER	4
SNAM S.P.A.	4
POLITECNICO DI TORINO	4
GERG LE GROUPE EUROPEEN DE RECHERCHES GAZIERES	4
Fundacion IMDEA Energia	4
ENGIE	4
AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE	4

Source: TIM, JRC, 2024.

Figure 44 shows the EU Member States participating in the projects assessed in Pillar 5. The size of the node represents the number of projects that has at least one participating organisation from that country. The thickness of the links between the nodes is proportional to the number of projects those countries have in common. As in previous years, Germany, France and Italy are involved in most of the projects, followed by Span Belgium, and the Netherlands. This dominance of west-EU countries is a constant for this Pillar. In addition, not shown explicitly by the graph, it is worth mentioning that among the non-EU countries, the most significant are the UK and Switzerland, which are involved in 6 and 4 projects, respectively.

Figure 44: TIM plot showing EU country participation in pillar 5 projects

Member State	Number of Projects
Italy	13
Germany	12
France	12
Spain	10
Belgium	9
Netherlands	6

Source: TIM, JRC, 2024.

Sustainability, LCSA, eco-design and recycling

BEST4HY successfully advanced recycling technologies for the material recovery of PEMFCs and SOFCs. The project met its recycling objectives, reaching recovery rates of 95 % of the platinum; at least 80 % of the SOFC anode materials, which include nickel and yttrium-stabilised zirconia; 80 % of the membrane ionomer; over 78 % of the lanthanum; and over 87 % of the cobalt. The project has also successfully met the 2024 target for platinum recovery and the 2030 target for ionomer recovery.

SH2E developed guidelines for LCSA and prospective benchmarking for hydrogen technologies, updating the methodology of FC-HyGUIDE. Additionally, guidelines for life cycle costing and social life cycle assessments have been produced. A software tool for conducting life cycle studies for hydrogen technologies has also been developed. Environmental LCA and life cycle costing assessment guidelines have already been released, with the LCSA guidelines expected by the end of the project.

eGHOST works on eco-design guidelines for PEMFCs and SOECs, and a white book for the eco-design of FCH products. So far, the project has performed a preliminary sustainability assessment of the two systems under study and applied the methodology for eco-design of energy-related products to the PEMFC case. Moreover, product concepts to improve the life cycle profile of PEMFCs and SOECs have been completed.

HyPEF will develop and test the first product environmental footprint category rules specific to FCH products. Product environmental footprint category rules are part of the European Commission's initiative to develop a common method for calculating the environmental footprint of products, known as the product environmental footprint. The HyPEF project aims to refine general product environmental footprint guidelines to suit the unique characteristics of FCH products.

NHyRA aims to address the quantities of hydrogen escaping into the atmosphere across the entire value chain by developing better ways to measure and calculate both small and large hydrogen releases. The project will create a comprehensive and accessible H_2 release inventory that can be used by scientists and industry professionals.

Education and public awareness

TEACHY established a European MSc course dedicated to FC and hydrogen technologies. The MSc course modules were used for continuous professional development courses with the participation of engineers and teachers.

HyAcademy EU aims to contribute to increasing skills in and knowledge of hydrogen technologies and systems, addressing, in this way, the urgent European need for high-quality educational curricula and a skilled workforce in this field. The project will form the basis of a future European Hydrogen Academy.

HYRESPONDER targeted a specific group of professionals: leaders and trainers of first-response teams. It completed the already available set of tools from the HYRESPONSE project (2013-2016) by providing a train-the-trainer programme in hydrogen safety throughout Europe.

HYPOP will address a gap identified in previous years in the field of social studies and public acceptance by providing other projects with practical guidelines and tools for increasing involvement of citizens, consumers, industrial end-users and other stakeholders. The final products will be engagement guidelines and a web platform at which communication materials will be gathered.

Safety, PNR and RCS

THYGA has tested how domestic and commercial gas appliances (boilers, burners and cookers) perform with hydrogen of up to 30 % in volume combined with NG. The project has completed an experimental campaign on approximately 100 appliances to identify the concentration limit below which hydrogen can be added to NG without changing existing certifications. The results showed that, for hydrogen of up to 20 % in volume combined with NG, the only safety risk identified is the possibility of delayed ignition for some specific designs.

SHIMMER aims to provide an integral approach to the consideration of material aspects, operative safety and understanding of hydrogen project risks and opportunities. One of the objectives is to define methods, tools and technologies for multi-gas network management and quality tracking.

THOTH2 will study the ability of instruments to accurately measure physical parameters of different H_2 and NG mixtures up to pure hydrogen level.

MultHyFuel aimed to develop guidelines for the design, construction and operation of refuelling stations able to refuel hydrogen vehicles and vehicles running on other fuels. The scope was limited to the forecourt and dispenser areas of refuelling stations, which are the parts to which the public has free access.

ELVHYS, building on the results of the PRESLHY project, will fill the knowledge gap on transfer of cryogenic hydrogen. The focus is not only on mobile applications such as refuelling of trucks and ships, but also on stationary tanks. The final product will consist of identification of the conditions and requirements allowing safe transfer.

e-SHyIPS deals with risk assessment methodologies and safety applied to passenger ships powered by hydrogen-based fuels. The final output will be a roadmap addressing techno-economic aspects, aiming at accelerating adoption of hydrogen as a fuel for passenger ships in the EU maritime sector.

PROJECT FACTSHEETS PILLAR 5

Sustainability, LCSA, eco-design and recycling

- BEST4HY
- SH2E
- eGHOST
- HyPEF
- NHyRA

Education and public awareness

- HyAcademy
- HYRESPONDER
- HYPOP

Safety, PNR and RCS

- THYGA
- SHIMMER
- THOTH2
- MultHyFuel
- ELVHYS
- e-SHyIPS

BEST4HY

SUSTAINABLE SOLUTIONS FOR RECYCLING OF END OF LIFE HYDROGEN TECHNOLOGIES

Project ID	101007216
PRR 2024	Pillar 5 – Cross-cutting
Call topic	FCH-04-4-2020: Development and validation of existing and novel recycling technologies for key FCH products
Project total costs	EUR 1 586 015.00
Clean H_2 JU max. contribution	EUR 1 586 015.00
Project period	1.1.2021–31.12.2023
Coordinator	Parco Scientifico Tecnologico per l'Ambiente SpA, Italy
Beneficiaries	Aktsiaselts Elcogen, Commissariat à l'énergie atomique et aux énergies alternatives, EKPO Fuel Cell Technologies GmbH (from March 2021), ElringKlinger AG (up to February 2021), Hensel Recycling GmbH, IDO-Lab GmbH, Politecnico di Torino, RINA Consulting SpA, Univerza v Ljubljani

https://best4hy-project.eu/

PROJECT AND GENERAL OBJECTIVES

The overall objective of Best4hy was to identify and develop viable recycling strategies, supported by innovative technologies, that will provide the best solution for material recovery from fuel cell and hydrogen (FCH) products (i.e. proton-exchange membrane fuel cells (PEMFCs) and solid oxide fuel cells (SOFCs)) and proof of concept for the recovery of iridium and palladium from proton-exchange membrane water electrolysis with novel technologies. The following specific objectives were set, according to the call challenges.

- Complete the adaptation and validation (in a relevant environment) of processes already used in conventional recycling and recovery centres to make them suitable for use in FCH commercial systems, including those involving key materials such as the platinum group metals.
- Complete the selection and validation (in a relevant environment) of at least two novel recycling techniques for key materials contained in FCH commercial products, such as PEMFCs / proton-exchange membrane water electrolysis, alkaline water electrolysis and SOFCs; the focus should be on recovering the precious metals used in the stacks as catalysts, reducing pre-consumer scraps, etc.
- Validate the suitability of the material(s) recovered for reintroduction into the supply chain of different FCH systems and/or different industrial sectors.
- Ensure the quality standards of industry in open-loop and/or closed-loop recycling applications.
- Undertake comprehensive environmental–economic analysis of the considered strategy.
- Overcome the main barriers of existing regulations.

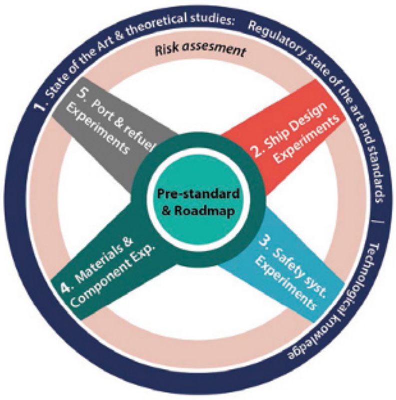
PROGRESS AND MAIN ACHIEVEMENTS

The Best4hy project developed a new gaseous-phase dismantling process for end-of-life (EOL) PEMFC processing, aiming to maximise the recovery of CCMs and achieve high recovery percentages of materials and components. Two patent applications were filed for the gaseous-phase dismantling process. The project also adapted a hydrometallurgical process and developed two novel processes for recovering Pt (as a salt precursor for PEMFCs), the ionomer and metallic Pt. High yields were achieved, with up to 95 % recovery for Pt and 80 % recovery for the ionomer. The recovered Pt salt was synthesised into a recycled catalyst for membrane electrode assembly production. CCMs were manufactured up to an industrial scale with 100 % recycled catalyst, showing good performance compared with that of commercial cells. A cradle-to-grave/gate-to-gate life-cycle assessment study was completed for both PEMFCs and SOFCs, adopting Best4hy recycling technologies and findings to support different EOL management scenarios and further research and development. All developed EOL processes, with their associated mass and energy balances, represent significant advances in SOFC manufacturing and EOL technologies.

FUTURE STEPS AND PLANS

The project has finished.

However, an exploitation strategy was developed for each of the 13 key exploitable results identified in the project. Partners are seeking opportunities to continue the development of the technology readiness level 5 technologies and to exploit the results commercially.



PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	Year for reported SOA result
Project's own objectives	GHGs in the overall production	%	– 20	– 20	✓	N/A
	La and Co recovery	%	> 80	La: > 78 %; Co: > 87 %		2023
	Pt recovered	%	90	95		2023
	Membrane	%	100	100		2022
	Pt recovered	%	80	95		2023
	Ionomer recovered	%	80	80		2023
	Anode material recovered overall for SOFCs	%	80	> 80		2023

SH2E

SUSTAINABILITY ASSESSMENT OF HARMONISED HYDROGEN ENERGY SYSTEMS: GUIDELINES FOR LIFE CYCLE SUSTAINABILITY ASSESSMENT AND PROSPECTIVE BENCHMARKING

Project ID	101007163
PRR 2024	Pillar 5 – Cross-cutting
Call topic	FCH-04-5-2020: Guidelines for life cycle sustainability assessment (LCSA) of fuel cell and hydrogen systems
Project total costs	EUR 2 142 778.75
Clean H_2 JU max. contribution	EUR 1 997 616.25
Project period	1.1.2021–30.6.2024
Coordinator	Fundación IMDEA Energía, Spain
Beneficiaries	Commissariat à l'énergie atomique et aux énergies alternatives, Forschungszentrum Jülich GmbH, Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón, GreenDelta GmbH, Institute of Applied Energy, Symbio, Symbio France

https://sh2e.eu/

PROJECT AND GENERAL OBJECTIVES

The goal of SH2E is to provide a harmonised (i.e. methodologically consistent) multidimensional framework for the life-cycle sustainability assessment (LCSA) of fuel cell and hydrogen (FCH) systems. To that end, SH2E will develop and demonstrate specific guidelines for the environmental, economic and social life-cycle assessments (LCAs) and benchmarking of FCH systems, while addressing their consistent integration into robust FCH LCSA guidelines. The aim is for these guidelines to be globally accepted as the reference document for the LCSA of FCH systems and to set the basis for future standardisation.

NON-QUANTITATIVE OBJECTIVES

- SH2E aims to contribute to FCH systems' sustainability. The development of harmonised guidelines will contribute to assessing the sustainability of FCH systems.
- The project aims to contribute to social acceptance. Better knowledge of FCH systems' social and environmental impacts will contribute to their acceptance.
- It aims to contribute to standardisation. Harmonised guidelines will pave the way for a standard.

PROGRESS AND MAIN ACHIEVEMENTS

- SH2E reviewed the existing guidelines.
- The project reviewed case studies and projects.
- Environmental LCA guidelines were issued.
- Life-cycle cost assessment guidelines were issued.
- Social LCA guidelines were issued.
- LCSA guidelines were issued (interim version).
- The software tool for performing FCH life-cycle studies was issued (interim version).

FUTURE STEPS AND PLANS

- LCSA guideline validation will be undertaken by an external party.
- The final version of the LCSA guidelines will be issued by the end of the project.
- The final version of the software tool will be issued by the end of the project.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	One integrated FCH LCA / LCC / social LCA / LCSA software tool	number	1	
	One document containing FCH LCSA guidelines with illustrative case studies after third-party review	number	1	
	Two FCH systems assessed and benchmarked	number	2	
	One document containing FCH LCA guidelines	number	1	✓
	One document containing FCH LCSA guidelines	number	1	✓
	Material criticality indicator	number	1	✓
	One document containing FCH LCC guidelines and one document containing FCH LCSA guidelines	number	2	✓

EGHOST

ESTABLISHING ECO-DESIGN GUIDELINES FOR HYDROGEN SYSTEMS AND TECHNOLOGIES

Project ID	101007166
PRR 2024	Pillar 5 – Cross-cutting
Call topic	FCH-04-3-2020: Development of eco-design guidelines for FCH products
Project total costs	EUR 1 133 541.25
Clean H_2 JU max. contribution	EUR 998 991.25
Project period	1.1.2021–31.5.2024
Coordinator	Fundación IMDEA Energía, Spain
Beneficiaries	Commissariat à l'énergie atomique et aux énergies alternatives, Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón, Institute of Applied Energy, Symbio, Symbio France, Univerza v Ljubljani

https://eghost.eu/

PROJECT AND GENERAL OBJECTIVES

eGhost will reach the first milestone in the development of ecodesign criteria in the European hydrogen sector. Two guidelines for specific fuel cell and hydrogen (FCH) products are being prepared, and the lessons learnt will be integrated into the eGhost white book: a reference guidance book for any future ecodesign project on FCH systems. It addresses the eco(re)design of mature products (proton-exchange membrane fuel cell (PEMFC) stacks) and those emerging with low technology readiness levels (solid oxide electrolysers) in such a way that sustainable design criteria can be incorporated from the earliest stages of product development.

NON-QUANTITATIVE OBJECTIVES

- eGhost aims to contribute to FCH systems' sustainability. Ecodesigning products will improve their sustainability performance.
- The project aims to contribute to social acceptance. Sustainable products are better accepted by end users and stakeholders, including civil society.

PROGRESS AND MAIN ACHIEVEMENTS

- The preliminary life-cycle sustainability assessment of the PEMFC stack is complete.
- The preliminary life-cycle sustainability assessment of the solid oxide electrolysis cell stack is complete.
- The PEMFC stack has been evaluated in accordance with the EU ecodesign directive.
- Product concepts have been completed.
- Product concepts will be assessed and prioritised as a function of the reduction goals.

FUTURE STEPS AND PLANS

- Methodological and technical ecodesign guidelines for the PEMFC stack will be issued (month 39).
- Methodological and technical ecodesign guidelines for the solid oxide electrolysis cells will be issued (month 39).
- The eGhost white book will contain the main recommendations for FCH products' eco(re)design, drawing on the lessons learnt (month 41).

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?	SOA result achieved to date (by others)	Year for reported SOA result
AWP 2020	Ecodesign guidelines	number	2		N/A	N/A
	Cumulative environmental reduction	%	10		18–44 % carbon footprint reduction	2013
	Cumulative cost reduction	%	3		From 2.6 % reduction to 46 %	2013
	Eco-efficiency improvement	%	10		N/A	N/A

HYPEF

PROMOTING AN ENVIRONMENTALLY-RESPONSIBLE HYDROGEN ECONOMY BY ENABLING PRODUCT ENVIRONMENTAL FOOTPRINT STUDIES

Project ID	101137575
PRR 2024	Pillar 5 – Cross-cutting
Call topic	HORIZON-JTI-CLEANH2-2023-05-01: Product environmental footprint pilot for a set of FCH product categories
Project total costs	EUR 1 499 431.25
Clean H_2 JU max. contribution	EUR 1 499 431.25
Project period	1.1.2024–31.12.2026
Coordinator	Fundación IMDEA Energía, Spain
Beneficiaries	Advanced Energy Technologies AE Ereunas & Anaptyxis Ylikon & Proiontonananeosimon Pigon Energeias & Synafon Symvouleftikon y Piresion, Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile, Ecoinnovazione SRL, Engie, Europäisches Institut für Energieforschung EDF-KIT EWIV, Hexagon Purus GmbH, Istituto di Studi per l'Integrazione dei Sistemi SCRL

https://www.hypef.eu/

PROJECT AND GENERAL OBJECTIVES

Fuel cell and hydrogen (FCH) systems are increasingly considered in energy and climate policies, roadmaps and plans all over the world. In order to avoid past criticalities, such as those leading to a climate emergency situation, sustainability criteria are being progressively implemented in these initiatives – for example, by promoting low-carbon, renewable hydrogen in Europe. In this regard, science-based criteria and procedures are required to guarantee the environmental suitability of FCH products, reporting their life-cycle environmental profile according to the principles of transparency, traceability, reproducibility and consistency for comparability. While these principles are aligned with those of the general methodological guidance for product environmental footprint (PEF) studies, further specification is required to effectively implement them when addressing FCH products. Therefore, the HYPEF project aspires to support and promote the establishment of an environmentally responsible hydrogen economy by developing and testing the first product environmental footprint category rules (PEFCRs) specific to FCH products, while paving the way for subsequent related initiatives in the FCH sector.

NON-QUANTITATIVE OBJECTIVES

HYPEF advancements are expected to have a very large international impact, as they will enable the running of similar PEF initiatives dealing with FCH product categories other than those addressed in HYPEF.

PROGRESS AND MAIN ACHIEVEMENTS

The interdisciplinary approach behind HYPEF has led to crucial advancements regarding (i) the first development and application of well-accepted PEFCRs tailored to three preselected FCH product categories (electrolysers for hydrogen production, tanks for hydrogen storage and fuel cells for hydrogen stationary use), (ii) increased high-quality data availability for consistent environmental assessment and benchmarking of FCH products and (iii) the first PEF-oriented policy recommendations regarding the official qualification of an FCH product as an environmentally responsible investment.

FUTURE STEPS AND PLANS

Current scientific efforts are focused on preparing the ground for FCH-PEFCRs by analysing relevant existing (PEF) category rules and exploring FCH systems for product categorisation. During the first year of the project, scientific efforts will also address the definition and selection of FCH product categories, the definition and screening PEF of the three representative products, and the set-up and management of the FCH-PEFCRs development process.

PROJECT TARGETS

Target source	Parameter	Target	Target achieved?
Project's own objectives	Set of policy recommendations based on the interplay between FCH PEFCRs and RCS	1	
	Sets of drafted FCH PEFCRs	3	
	Life-cycle environmental profiles calculated for FCH products	12	
	List of FCH product categories	1	
	LCIs ready for implementation in the LCDN	12	

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NHYRA

PRE-NORMATIVE RESEARCH ON HYDROGEN RELEASES ASSESSMENT

Project ID	101137770
PRD 2024	Pillar 5 – Cross-cutting
Call topic	HORIZON-JTI-CLEANH2-2023-05-03: Pre-normative research on the determination of hydrogen releases from the hydrogen value chain
Project total costs	EUR 2 086 683.75
Clean H_2 JU max. contribution	EUR 2 086 683.75
Project period	1.1.2024–31.12.2026
Coordinator	Snam SpA, Italy
Beneficiaries	Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile, Alma Mater Studiorum – Università di Bologna, Deutsches Zentrum für Luft- und Raumfahrt EV, Enagás Transporte SA, Engie, Equinor Energy As, Fondazione Bruno Kessler, Groupe Européen de Recherches Gazières, Instytut Nafty i Gazu – Państwowy Instytut Badawczy, Linde GmbH, NPL Management Limited, Nuovo Pignone Tecnologie SRL, Regents of the University of California, University of Surrey

https://cordis.europa.eu/project/id/101137770

PROJECT AND GENERAL OBJECTIVES

Several studies and analyses show that by 2050 hydrogen will become a pillar of the future energy system, representing up to 20 % of the future energy demand, and with this it is expected that anthropogenic H_2 emissions, which have an indirect impact on the greenhouse effect, will also increase.

Furthermore, there are currently large uncertainties regarding both the total amount of hydrogen that will be released from the H_2 value chain and the climate effect of the hydrogen released into the atmosphere.

The general objective of the project NHYRA is to perform an assessment of potential H_2 releases along the entire H_2 value chain. In particular, the project aims to:

- fill the critical knowledge gaps regarding technologies, methodologies and protocols for detecting and quantifying H_2 releases;
- develop H_2 release scenarios that will allow for the identification of the most critical elements of the H_2 value chain in terms of emissions;
- propose mitigation strategies, guidelines and recommendations for standardisation bodies in order to support the definition of a dedicated normative framework.

PROGRESS AND MAIN ACHIEVEMENTS

The NHYRA consortium organised a first workshop with the Hybrid power-energy electrodes for next generation lithium-ion batteries (HYDRA) project, during which the two projects presented their work and started discussions on how to cooperate, while considering each project's timeline, objectives and deliverables.

FUTURE STEPS AND PLANS

One of the central elements of the NHYRA project, and also one of the first activities that will take place, is the creation of a H_2 release inventory.

The first work package will involve an initial literature review and the collection of data and information from H_2 technologies, systems and infrastructure operators, which will lead to the identification of the most relevant H_2 supply chain and the most critical elements of the H_2 value chain in terms of H_2 emissions.

From these findings, dedicated methodologies will be developed with the initial aim of determining suitable techniques and instruments for the detection and measurement of hydrogen leakages. Then, measurement-based methods will be developed for detecting and quantifying H_2 emissions, considering both fugitive and vented emissions; calculation-based methods will also be developed to enable the estimation of hydrogen emissions when taking direct measurements is impossible or too complicated (as, for example, in the case of an accident or unburned fuel).

The methodologies developed will then be tested for validation, both in laboratories and in real cases, and the experimental data collected will feed the H_2 release inventory.

NHYRA will quantify the total potential H_2 releases along each H_2 supply chain and will develop mitigation strategies.

Finally, H_2 release scenarios that include all H_2 supply chains will be developed, considering various time horizons.

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PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Workshop on H_2 production with overview of H_2 leakage in production	number	1	
	Workshop on H_2 transport and storage with overview of H_2 leakage	number	1	
	Workshop on H_2 end use with overview of H_2 leakage in end use	number	1	
	Engagement with EU/national associations	number	2	
	Invitation to join the Advisory Board sent to providers of H_2 detection technology and equipment manufacturers	number	1	
	Dissemination in Clean Hydrogen Mission countries and at universities in at least nine countries	number	9	
	Communication toolkit tailored to a non-technical audience	number	1	
	Workshop presenting results relevant to policymakers	number	1	
	Number of archetype technologies assessed in terms of H_2 releases and implemented in the simulation tool	number/ project	12	
	Measurement-based methods for detecting hydrogen emissions from individual elements of the value chain	number/ project	2	
	Measurement-based methods for quantifying fugitive or vent emissions from point or subarea sources	number/ project	2	
	H_2 release inventory	number/ project	1	
	Participation in one conference on energy markets/finance to engage with financial stakeholders	number	1	
	Presentation at suitable measurement-related conference (e.g. CEM)	number	1	
	At least two meetings with standardisation committees	number	2	

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HYACADEMY.EU

THE EUROPEAN HYDROGEN ACADEMY

Project ID	101137988
PRR 2024	Pillar 5 – Cross-cutting
Call topic	HORIZON-JTI-CLEANH2-2023-05-02: European Hydrogen Academy
Project total costs	EUR 2 987 233.75
Clean H_2 JU max. contribution	EUR 2 987 233.75
Project period	1.1.2024–30.6.2028
Coordinator	Vysoká škola chemicko-technologická v Praze, Czechia
Beneficiaries	Bertz Associates Ltd, Deutscher Verein des Gas- und Wasserfaches – Technisch-wissenschaftlicher Verein EV, EUREC EESV, Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón, Future. Solutions SÀRL, KIC InnoEnergy SE, Politecnico di Torino, Rijksuniversiteit Groningen, Technokrati Ltd, Trakiyski universitet, Università degli Studi di Modena e Reggio Emilia, Universitatea Politehnica din Bucureşti, Université de technologie de Belfort-Montbéliard, Université libre de Bruxelles, University of Birmingham, University of Ulster

http://www.hyacademy.eu

PROJECT AND GENERAL OBJECTIVES

Hyacademy.EU will coordinate and support the delivery of hydrogen education and training across a network of over 600 educational institutions, providing education to over 5 000 individuals and tens of thousands of school children and young adults. It will establish a network of more than five joint training laboratories for hydrogen technologies.

Hyacademy.EU will capitalise on the European Commission's and Member States' investments in education and training activities. The consortium brings together representatives from multiple projects, enabling previous outputs to be consolidated and exploited, maximising the academy's impact and reach.

To realise its objectives, by the project midterm, the European Hydrogen Academy aims to:

- build and sustain a network of over 100 universities (the 'Network100') offering recognised qualifications, specialisations and degrees in hydrogen technologies;
- build and sustain a network of over 500 schools integrating hydrogen topics into their science teaching, including technical schools and colleges offering more specific technical training;
- create a network of five hands-on, physical training laboratories;
- offer a portal to showcase and link the educational programmes available in the network and beyond in order to supply prospective trainees with accurate and detailed information on training and career opportunities, allowing them to access documents focused on hydrogen topics at least 100 000 times;
- provide lecturers and teachers with free training materials in all EU languages to enable educational staff to deliver the vast body of educational measures necessary;
- develop and integrate novel (online) teaching methodologies into university, college and school curricula and train educational staff to successfully employ these;
- create and implement an organisational structure and a successful business case allowing for the post-funding continuation of the project activities establishing a European Hydrogen Academy spanning all levels and types of education and training.

Hyacademy.EU will considerably contribute to the EU goals of offering access to high-quality education, thus supporting the creation of a highly skilled workforce and more and better jobs in the European hydrogen industry. Through the school activities, it will foster public awareness and acceptance of hydrogen technologies.

PROGRESS AND MAIN ACHIEVEMENTS

- Universities, technical schools, training institutions and schools are currently being contacted for information.
- Network membership is being offered.
- Full website went live at the end of June 2024.
- First version of the database went online at the end of June 2024.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	Year for reported SOA result
Project's own objectives	Network of schools (Network500)	schools participating in network	500	50		2023
	Network of universities (Network100)	universities participating in network	105	30		2023
	Pupils trained	pupils trained	5 000	N/A		N/A
	Social media followers	followers	3 500	N/A		2023
	Training laboratory network	laboratories in network	5	3		2023
	Access to project website	access requests	100 000	50		2023
	Platform users	registered users	5 000	N/A		2023

HYRESPONDER

EUROPEAN HYDROGEN TRAIN THE TRAINER PROGRAMME FOR RESPONDERS

Project ID	875089
PRR 2024	Pillar 5 – Cross-cutting
Call topic	FCH-04-1-2019: Training of responders
Project total costs	EUR 1 000 000.00
Clean H_2 JU max. contribution	EUR 1 000 000.00
Project period	1.1.2020–31.5.2023
Coordinator	University of Ulster, United Kingdom
Beneficiaries	Association Comité National Français du Comité Technique International de Prévention et d'Extinction du Feu, Ayuntamiento de Zaragoza, Commissariat à l'énergie atomique et aux énergies alternatives, Crisis Simulation Engineering SARL, Deutsches Zentrum für Luft- und Raumfahrt EV, DLR-Institut für Vernetzte Energiesysteme EV, École nationale supérieure des officiers de sapeurs-pompiers, Fire Service College Limited, International Fire Academy, L'Air Liquide SA, Landes-Feuerwehrverband Tirol, Ministry of the Interior of the Czech Republic, Persee, Service Public Fédéral Intérieur, Università degli Studi di Roma 'La Sapienza', Universitetet i Sørøst-Norge

https://hyresponder.eu/

PROJECT AND GENERAL OBJECTIVES

The aim of Hyresponder was to develop and implement a sustainable trainers' programme on hydrogen safety for responders throughout Europe. The updated operational, virtual reality and educational training reflects state-of-the-art hydrogen safety. The *European Emergency Response Guide* has been revised. Translated materials for responders are available in eight languages via a purpose-built e-platform. The translated materials will be utilised by trainers to deliver workshops and impact training nationally in 10 European countries, enhancing the reach of the programme.

NON-QUANTITATIVE OBJECTIVES

- Hyresponder aimed to embed elements of the training at the national level. Each country has a short- to medium-term plan to maximise the impact during and beyond Hyresponder.
- The project aimed to develop a formal module/certificate. A draft document has been prepared with the key learning outcomes, content, etc., which will be trialled by some partners during national training.
- It aimed to develop training packages at different levels. Stratified educational materials are now available.

PROGRESS AND MAIN ACHIEVEMENTS

- A beta version of the Hyresponder e-platform with stratified training materials and tools is available online.
- Responder trainers from 10 partner countries have been trained in hydrogen safety.
- Novel online training sequences have been developed to support the remote training of responders.
- Three activities have been evaluated by the Innovation Radar: the e-platform to support training of responders in hydrogen safety (https://www.innoradar.eu/innovation/44458), stratified training materials for responders spanning four learning levels (https://www.innoradar.eu/innovation/44457) and the novel training sequences to support online training of responders (https://www.innoradar.eu/innovation/44454). In addition, translated material is now available on the e-platform under 'Training materials'.
- Hyresponder delivered regional workshops.
- The project completed the translation of training materials.
- Hyresponder demonstrated the project's impact within each country. Each partner had a plan to ensure that the Hyresponder training had an impact within and beyond the project.
- Within Hyresponder, trainers from across Europe have undertaken online (June 2021) and operational (June 2022) training. In turn, the trainers have used this training to deliver training in their regions, as part of Hyresponder, but also to ensure a plan is in place beyond the project.

FUTURE STEPS AND PLANS

The project has finished.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objectives	Materials translated into eight languages	number	8	8, but not all elements	✓
	Threefold training materials (lectures, operational training, VR)	number	3	3	
	e-Platform for responders	number	1	1	
	Train-the-trainer activities for all trainers and 10 national training events	number	12	12	
	Revised *European Emergency Response Guide*	number	1	1	

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HYPOP

HYDROGEN PUBLIC OPINION AND ACCEPTANCE

Project ID	101111933
PRR 2024	Pillar 5 – Cross-cutting
Call topic	HORIZON-JTI-CLEANH2-2022-05-01: Public understanding of hydrogen and fuel cell technologies
Project total costs	EUR 1 062 755.00
Clean H_2 JU max. contribution	EUR 1 062 754.50
Project period	1.6.2023–31.5.2025
Coordinator	Parco Scientifico Tecnologico per l'Ambiente SpA, Italy
Beneficiaries	Agenzia per la Promozione della Ricerca Europea, Balkanski Vodoroden Klaster, Centro Nacional de Experimentación de Tecnologías de Hidrógeno y Pilas de Combustible Consorcio, Cluster TWEED, Fundación IMDEA Energía, Institute for Methods Innovation, Regionalna Izba Gospodarcza Pomorza

http://www.hypop-project.eu/

PROJECT AND GENERAL OBJECTIVES

Project HYPOP will support hydrogen deployment in Europe by enhancing the involvement of citizens and providing guidelines to increase trust in hydrogen implementation. Clear communication will be key to hydrogen technological development with social acceptance. HYPOP's overall objective is to raise public awareness of and trust in hydrogen technologies and their systemic benefits, through (i) the preparation of guidelines and good practices that will help to define more effectively how citizens, consumers / end users and stakeholders can be involved in the implementation of H_2 technologies and (ii) the creation of a web platform collecting communication material (mainly videos) on new hydrogen technologies, developed based on the early findings of the public engagement activities. HYPOP will focus on two applications of hydrogen technologies that will enter people's daily lives: residential and mobility.

NON-QUANTITATIVE OBJECTIVES

- An assessment of current public opinion on hydrogen technologies will be undertaken, resulting in a final scientific paper to share with the stakeholders and the scientific community.
- HYPOP will improve the availability of information, citizens' understanding of their own roles in hydrogen implementation, and citizens' abilities to understand the topic of hydrogen and develop their own opinions on it and the transition strategy. Part of the information will come from the stakeholders' consultation and direct involvement in HYPOP.

PROGRESS AND MAIN ACHIEVEMENTS

- **Analysis of Member States' H_2 strategies to assess hydrogen implementation in Europe.** The analysis also focuses on hydrogen-related public engagement activities at the national, regional and local levels (projects and hydrogen valleys).
- **Analysis of survey data and public perceptions.** Secondary data analysis of the Public Opinion Survey (Clean Hydrogen Joint Undertaking, May 2023) and state-of-the-art analysis of public perceptions and reactions to hydrogen and fuel cell technologies are ongoing.
- **Analysis of public engagement with H_2 via social media across the EU.** This included the identification of the main individual-level determinants of public understanding and acceptance of fuel cell and hydrogen technologies.
- **Stakeholders' requirements for H_2 technology installation.** These are mainly permit-issuing, certification and safety requirements.

FUTURE STEPS AND PLANS

- Citizens' engagement workshops in each of the HYPOP countries (Belgium, Bulgaria, Ireland, Spain, Italy, Poland) and two international events to inform citizens about the project and increase public trust in H_2 implementation.
- Stakeholders' engagement workshops in each of the HYPOP countries to report the results from the requirement lists for permit issuing, safety and certification analysis.
- One public-oriented guideline reporting best practices to involve citizens.
- Three guidelines collecting the results coming from the involvement of stakeholders' groups (first responders, permitting authorities, certification body).
- A web platform gathering information on hydrogen projects and related initiatives.
- Videos and infographics to support the HYPOP hydrogen awareness campaign.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Trained professionals in tier 2 countries (Austria, Belgium, Finland, Italy, Latvia, the Netherlands, Norway, Spain and Sweden)	number	> 50	
	Trained professionals in tier 3 countries (rest of the Member States and associated countries)	number	> 30	
	Number and type of target groups engaged	number	> 3/country across the six HYPOP countries (including one industrial group)	

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THYGA

TESTING HYDROGEN ADMIXTURE FOR GAS APPLICATIONS

Project ID	874983
PRR 2024	Pillar 5 – Cross-cutting
Call topic	FCH-04-3-2019: Hydrogen admixtures in natural gas domestic and commercial end uses
Project total costs	EUR 2 468 826.25
Clean H_2 JU max. contribution	EUR 2 468 826.25
Project period	1.1.2020–31.3.2023
Coordinator	Engie, France
Beneficiaries	BDR Thermea Group BV, Commissariat à l'énergie atomique et aux énergies alternatives, Dansk Gasteknisk Center A/S, Deutscher Verein des Gas- und Wasserfaches – Technisch-wissenschaftlicher Verein EV, Electrolux Italia SpA, Gas.be, Gaswärme-Institut Essen EV, Groupe Européen de Recherches Gazières

https://thyga-project.eu/

PROJECT AND GENERAL OBJECTIVES

The THYGA project investigated the amount of hydrogen that can be injected without compromising the safety, emissions and efficiency of existing and new applications. It focused on the end-user perspective, specifically domestic and commercial gas appliances (space heating, hot water, cooking and catering), which account for > 40 % of the EU's gas consumption. The objectives were to close knowledge gaps on the impact blends of H_2 and natural gas (NG), support standardisation activities and identify potential mitigation opportunities.

NON-QUANTITATIVE OBJECTIVES

- THYGA aimed to involve external partners in the project. Some laboratories and manufacturers expressed their wish to use the THYGA protocol to create their own tests and contribute to the analysis.
- The project aimed to have an international reach. THYGA's test protocol has been requested for use as a test reference by international partners (in Canada, Chile and the United States).

PROGRESS AND MAIN ACHIEVEMENTS

- THYGA tested around 100 appliances, including as part of the preparation of reports for work packages 4 (standardisation) and 5 (mitigation).
- Eighteen public deliverables/newsletters were created and distributed, and seven public workshops organised.
- The project completed its test campaign objectives, with more than 100 appliances (burners) tested, by March 2023.
- THYGA gained support regarding standardisation from stakeholders: European Committee for Standardization technical committees (CEN/TCs), manufacturer associations, notified bodies and national/European technical associations.
- The project identified technical issues linked to H_2 injection into natural gas at different rates and proposed several mitigation methodologies to improve the rate of H_2 injection with which appliances can deal (in terms of safety, efficiency, power, etc.).
- Results were disclosed during the final workshop on 24 March 2023. All results are published on the THYGA website, the results have been disseminated to CEN/TCs and the THYGA experts will be available for further enquiries on the topic.

FUTURE STEPS AND PLANS

The project has finished.

PROJECT TARGETS

Target source	Parameter	Achieved to date by the project	Target achieved?	SOA result achieved to date (by others)	Year for reported SOA result
Project's own objectives	Understanding of the actual, theoretical and experimental knowledge regarding the impact of H_2NG blends on combustion	12 public deliverables		Several studies and test reports	2020
	Understanding of the actual, theoretical and experimental knowledge regarding the impact of H_2NG blends on materials	Theoretical and practical reviews released		Several studies and test reports	2020
	Segmentation of the types of appliances	Segmentation validated with stakeholders (Advisory Panel Group)		Similar approaches on segmentation	2020
	Tests of appliances	100 % of tests done	✓	Similar evaluations for national projects (GRHYD, Hydeploy, Hydelta)	2020, 2021, 2022, 2023
	Establishing how the existing certification will be modified to allow higher concentrations, including the related additional costs and the required changes to common gas burners	SOA reports (deliverables 4.1 and 4.2)		CEN/TCs' activities and other projects (Hydelta)	2020, 2021, 2022
AWP 2018	Recommendations for revision of European or ISO standards or drafting of new standards based on PNR results and a review of the existing testing methods	Public deliverable 4.3 published, which includes recommendations, based on test gases, if the current framework is to be kept and provides insights on the risks to be assessed with H2NG blends		CEN/TCs' activities and other projects (Hydelta)	2022, 2023

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SHIMMER

SAFE HYDROGEN INJECTION MODELLING AND MANAGEMENT FOR EUROPEAN GAS NETWORK RESILIENCE

Project ID	101111888
PRD 2023	Pillar 5 – Cross-cutting
Call topic	HORIZON-JTI-CLEANH2-2022-05-03: Safe hydrogen injection management at network-wide level: towards European gas sector transition
Project total costs	EUR 3 037 265.00
Clean H_2 JU max. contribution	EUR 2 999 156.25
Project period	1.9.2023–31.8.2026
Coordinator	SINTEF AS, Norway
Beneficiaries	Bundesanstalt für Materialforschung und -prüfung, Enagás Transporte SA, Fundacion Tecnalia Research and Innovation, Gassco AS, Groupe Européen de Recherches Gazières, INRETE Distribuzione Energia SpA, Instytut Nafty i Gazu – Państwowy Instytut Badawczy, Nederlandse Organisatie voor toegepast natuurwetenschappelijk onderzoek, Operator Gazociągów Przesyłowych GAZ-SYSTEM S.A., Politecnico di Torino, Redexis Gas Servicios SL, Redexis SA, Snam SpA

https://shimmerproject.eu/

PROJECT AND GENERAL OBJECTIVES

To accelerate the transition to a low-carbon economy while exploiting existing infrastructure, hydrogen can be injected into the natural gas network. However, there are many technical and regulatory gaps that should be closed and adaptations and investments that should be made to ensure that multigas networks across Europe will be able to operate in a reliable and safe way while providing gas of highly controllable quality and meeting energy demand. Recently, the European Committee for Standardization concluded that it was impossible to set a common limiting value for hydrogen injected into the European gas infrastructure, instead recommending a case-by-case analysis. In addition to this, there are still uncertainties related to the material integrity of pipelines and network components with regard to their reduced lifetimes in the presence of hydrogen.

Results from previous and ongoing projects on the hydrogen readiness of grid components should be summarised in a systematic manner together with the assessment of the existent transmission and distribution (T & D) infrastructure components at the European level to provide stakeholders with decision support and risk reduction information to drive future investments and the development of regulations and standards.

The Shimmer project aims to enable higher levels of hydrogen integration and safer hydrogen injection management in multigas networks by contributing to the knowledge and better understanding of hydrogen projects and their risks and opportunities.

NON-QUANTITATIVE OBJECTIVES

- To map and address the European gas T & D infrastructure in relation to materials, components and technologies and their readiness for hydrogen blends.
- To define methods, tools and technologies for multigas network management and quality tracking – including simulation, prediction and safe management of transients – with a view to widespread hydrogen injection across Europe.
- To propose best-practice guidelines for safely handling hydrogen in the natural gas infrastructure and managing the risks.

PROGRESS AND MAIN ACHIEVEMENTS

The technical work during the first month has started in two work packages.

WP3 - Integrity Management and Safety

- Gathering information about materials and components in natural gas grids of participating TSOs and DSOs.
- Identifying critical material properties and component factors.
- Reviewing existing in-line inspection methods and involving technology providers in test campaigns.
- Gathering information on common leakage detection methods among operators.

WP4 - Flow Assurance

- Defines network models and case studies.
- Several workshops were held with TSOs and DSOs.
- A realistic case requirement document of needed components and data was achieved.
- Next phase focuses on collecting input data and finalizing case and model definitions.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Capability to control hydrogen presence over a served area	km^2	TSOs: > 100 DSOs: > 5	
	Trained professionals	number	Tier 1: 120 000 Tier 2: 40 000 Tier 3: 20 000	
	Capability to track hydrogen spreading through the network structure	$\Delta\%H_2/h$ $\Delta\%H_2/km^2$	< 1 % < 2 %	
SRIA (2021–2027)	Total capital investment	M€/km	0.8	
	Operational expenditure pipeline	€/kg	0.01	
	Projects with proactive safety management	number	100	
	H_2 leakage	%	0	
	Safety, PNR/RCS workshops	number/year	4	
AWP 2018	Impact on standards at scope	number/project	1	

THOTH2

NOVEL METHODS OF TESTING FOR MEASUREMENT OF NATURAL GAS AND HYDROGEN MIXTURES

Project ID	101101540
PRR 2024	Pillar 5 – Cross-cutting
Call topic	HORIZON-JTI-CLEANH2-2022-05-04: Development of validated test methods and requirements for measuring devices intended for measuring NG/H_2 mixtures
Project total costs	EUR 1 997 361.25
Clean H_2 JU max. contribution	EUR 1 997 360.50
Project period	1.2.2023–31.7.2025
Coordinator	Snam SpA, Italy
Beneficiaries	Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile, Alma Mater Studiorum – Università di Bologna, Cesame-Exadébit SA, Commonwealth Scientific and Industrial Research Organisation, Eidgenössisches Institut für Metrologie METAS, Enagás Transporte SA, Fondazione Bruno Kessler, Groupe Européen de Recherches Gazières, GRTgaz, INRETE Distribuzione Energia SpA, Instytut Nafty i Gazu – Państwowy Instytut Badawczy, Istituto Nazionale di Ricerca Metrologica, Operator Gazociągów Przesyłowych GAZ-SYSTEM S.A.

https://thoth2.eu/

PROJECT AND GENERAL OBJECTIVES

Thoth2 aims to cover the normative and standards gaps related to methodologies and protocols for evaluating the performances and identifying the limits and tolerances of state-of-the-art (SOA) measuring devices in transmission and distribution systems when carrying mixtures of H_2 and natural gas (NG) or pure H_2. Thoth2 will design dedicated methodologies to test types of measuring devices (gas metres, gas volume conversion devices, pressure and temperature transducers, gas quality analysers and gas leak detectors) under various operating conditions.

NON-QUANTITATIVE OBJECTIVES

The Thoth2 project will help the scientific and industrial communities understand the potential impact of different H_2NG mixtures on the performances of SOA measuring devices installed in the transmission and distribution gas infrastructure. European transmission system operators (TSOs) and distribution system operators (DSOs) will benefit from the project results, as they will obtain important information about the limits and tolerances of the measuring instruments under various operating conditions. As Shimmer is a pre-normative research project, recommendations will be sent to the normative bodies to support the development of new standards and the updating of existing ones.

PROGRESS AND MAIN ACHIEVEMENTS

Within work package (WP) 1, the SOA, barriers and bias of metering devices for NG blends and pure H_2 have been assessed. Three deliverables (public reports) describe the analysis performed.

The definition of the methodologies for testing the measuring devices is in progress (under WP 2). They will then be applied in the validation of selected devices in order to evaluate the devices' performances under various operating conditions (WP 3).

FUTURE STEPS AND PLANS

Once the methodologies have been defined the next step will be to apply these methodologies/protocols to a list of selected measuring devices. These measuring devices have been selected based on the analysis performed in WP 1 in order to represent the most typical/common devices and systems installed in the gas infrastructure operated by the TSOs and DSOs involved in the project and in the analysis previously performed. The test activities will validate the methodologies and provide data that will be included in the recommendations. These recommendations will then be shared with standardisation bodies and manufacturers through the Stakeholder Advisory Board of the Thoth2 project.

PROJECT TA RGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objectives	Organisation of at least one Stakeholder Advisory Board workshop	number	1	1	✓
	Four papers submitted to gold open access peer-reviewed journals during the project	number	4	1	
	Presentation of the project at at least five professional workshops/exhibitions	number	5	3	
	Articles submitted to the popular press or trade journals to enable other stakeholders to understand and have access to the results of the project	number	3	0	
	Organisation of a closing workshop to present the project results to all interested stakeholders	number	1	N/A	
	Presentation of at least seven papers at international conferences and other relevant conferences identified during the project	number	7	3	
	Impact on standards at scope	number	1	N/A	
	Safety, PNR/RCS workshops	number	2	1	

Clean Hydrogen Partnership
Co-funded by the European Union

MULTHYFUEL

MULTI-FUEL HYDROGEN REFUELLING STATIONS (HRS): A CO-CREATION STUDY AND EXPERIMENTATION TO OVERCOME TECHNICAL AND ADMINISTRATIVE BARRIERS

MultHyFuel

Project ID	101006794
PRR 2024	Pillar 5 – Cross-cutting
Call topic	FCH-04-1-2020: Overcoming technical and administrative barriers to deployment of multi-fuel hydrogen refuelling stations (HRS)
Project total costs	EUR 2 121 906.25
Clean H_2 JU max. contribution	EUR 1 997 406.25
Project period	1.1.2021–30.09.2024
Coordinator	Hydrogen Europe, Belgium
Beneficiaries	Engie, Health and Safety Executive, Institut national de l'environnement industriel et des risques, ITM Power (Trading) Limited, Kiwa Nederland BV, L'Air Liquide SA, Shell Nederland Verkoopmaatschappij BV, Snam SpA, Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg

https://multhyfuel.eu/

PROJECT AND GENERAL OBJECTIVES

Multhyfuel's ultimate goal is the amendment of best-practice guidelines for the design, construction and development of multifuel refuelling stations. An analysis of the current legal framework regarding permitting requirements throughout Europe has been carried out. A risk assessment analysis and the experimental data acquisition on the leakage characteristics and consequences in the station's forecourt will take place shortly.

NON-QUANTITATIVE OBJECTIVES

The project aims to contribute to the harmonisation of permitting and risk assessment requirements by developing best-practice guidelines based on new data acquired during project implementation.

PROGRESS AND MAIN ACHIEVEMENTS

Deliverable 1.2 – Permitting requirements and risk assessment methodologies for HRS in the EU (first version) was submitted and presented to the stakeholders, with a summary of the main commonalities and differences found in permitting requirements from 14 European countries.

Feedback from public authorities was received, as was feedback from experts during the interim review meeting. In work package (WP) 3, three case study models with different configurations were identified and designed, and a preliminary risk assessment was performed on them to identify the most critical scenarios to study in WP 2. In WP 2, *Deliverable 2.2 – Assessment of dispersion for high-pressure H_2* was submitted, with results from computational fluid dynamics modelling simulations performed to evaluate the size of clouds expected considering different scenarios of leakage in H_2 dispensers. Testing was performed to acquire data concerning leakage characteristics and consequences, and results were presented to targeted stakeholders.

FUTURE STEPS AND PLANS

Considering new data acquired during experimental testing, the consortium will review the risk assessment performed at the beginning of the project and develop a set of best-practice guidelines, which will be presented to hydrogen refuelling station operators, public authorities and standardisation bodies.

PROJECT TARGETS

Target source	Parameter	Unit	Achieved to date by the project	Target achieved?	SOA result achieved to date (by others)	Year for reported SOA result
Project's own objectives	Safety refuelling distance	m	N/A		5–35, depending on the country	2021
	Guidelines for safety barriers	-	N/A		Depending on the country	N/A
	Number of stakeholders endorsing project's results	number of authorities	17		N/A	N/A

ELVHYS

ENHANCING SAFETY OF LIQUID AND VAPORISED HYDROGEN TRANSFER TECHNOLOGIES IN PUBLIC AREAS FOR MOBILE APPLICATIONS

Project ID	101101381
PRR 2024	Pillar 5 – Cross-cutting
Call topic	HORIZON-JTI-CLEANH2-2022-05-02: Safety of cryogenic hydrogen transfer technologies in public areas for mobile application
Project total costs	EUR 1 433 960.00
Clean H_2 JU max. contribution	EUR 1 433 960.00
Project period	1.1.2023–31.12.2025
Coordinator	Norges teknisk-naturvitenskapelige universitet, Norway
Beneficiaries	Alma Mater Studiorum – Università di Bologna, Deutsches Zentrum für Luft- und Raumfahrt EV, Health and Safety Executive, Karlsruher Institut für Technologie, L'Air Liquide SA, National Centre for Scientific Research 'Demokritos', University of Ulster

https://elvhys.eu/

PROJECT AND GENERAL OBJECTIVES

The Elvhys project addresses a critical gap in international standards related to liquid and cryogenic hydrogen transfer technologies for mobile applications, such as filling trucks, ships and stationary tanks. Currently, there is limited or no experience in this area, which poses significant challenges for safety and efficiency in hydrogen transfer operations.

The overarching objective of Elvhys is to develop inherently safer and more efficient liquid and cryogenic hydrogen technologies and protocols for mobile applications. This objective is pursued through innovative safety strategies and engineering solutions, including the selection of effective safety barriers and hazard-zoning strategies. The project utilises an interdisciplinary approach, combining experimental, theoretical and numerical studies to address various aspects of liquid and cryogenic hydrogen transfer.

NON-QUANTITATIVE OBJECTIVES

- The results of Elvhys will contribute to many objectives of the Clean Hydrogen Joint Undertaking strategic research and innovation agenda, such as increasing the level of safety and supporting the development of regulations, codes and standards (RCSs) for hydrogen technologies and applications.
- Increasing the level of safety of hydrogen technologies and applications is the cornerstone of the entire Elvhys project. It will be addressed by performing cutting-edge research, closing numerous knowledge gaps in the understanding of the underlying liquid hydrogen (LH_2) transfer physical phenomena of heat and mass transfer at cryogenic temperatures and under multiphase flow conditions, advancing the SOA through the generated knowledge, developing innovative prevention and mitigation strategies and proposing risk-informed recommendations and guidelines on cryogenic hydrogen transfer technologies.
- The objective of supporting the development of RCSs for hydrogen technologies and applications, with a focus on standards, will be addressed through the developed science-based recommendations for RCSs, beyond the SOA guidelines and fuelling/bunkering/transfer procedures.

PROGRESS AND MAIN ACHIEVEMENTS

The Elvhys project's progress regarding LH_2 transfer technologies is as follows.

- Operational data collection and best practices in LH_2 transfer. Extensive data collection efforts made to identify best practices in LH_2 transfer operations.
- LH_2 transfer ecosystem, infrastructures and applications. Comprehensive overview of the LH_2 transfer ecosystem provided.
- Piping and instrumentation diagrams of LH_2 transfer installations and list of existing safety devices. Detailed piping and instrumentation diagrams developed for LH_2 transfer installations.
- Refined research programme on the safety of LH_2 transfer systems. Refined research programme developed to focus on the safety aspects of LH_2 transfer systems.
- Review of methodologies, preliminary risk analysis and gap identification. Preliminary risk analysis of specific scenarios conducted to identify gaps and areas for further investigation.
- Compilation of relevant/existing RCSs and bodies. Comprehensive list of relevant RCSs and regulatory bodies compiled for LH_2 transfer operations.
- Support of LH_2 fire and explosion tests through modelling. Computational models selected to provide insights into potential hazards and mitigation strategies.
- Experiment set-up and test readiness review for fire tests and boiling liquid expanding vapour explosion tests on LH_2 hoses.
- Hazard identification for LH_2 transfer operations. Detailed identification of potential risks and proposed mitigation strategies completed.

FUTURE STEPS AND PLANS

The Elvhys project aims to provide a supportive regulatory and standardisation framework.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?	SOA result achieved to date (by others)	Year for reported SOA result
SRIA (2021–2027)	Impact on standards at scope	number/project	1		0.6	2020
	Safety, PNR/RCS workshops	number/year	2	✓	1	2020

JUST-GREEN AFRH2ICA

PROMOTING A JUST TRANSITION TO GREEN HYDROGEN IN AFRICA

Project ID	101101469
PRR 2024	Pillar 5 – Cross-cutting
Call topic	HORIZON-JTI-CLEANH2-2022-05-05: Research & innovation co-operation with Africa on hydrogen
Project total costs	EUR 999 995.00
Clean H_2 JU max. contribution	EUR 999 995.00
Project period	1.2.2023–31.1.2025
Coordinator	Università degli Studi di Genova, Italy
Beneficiaries	African Hydrogen Partnership, Artelys, BluEnergy Revolution SCRL, Commissariat à l'énergie atomique et aux énergies alternatives, Forschungszentrum Jülich GmbH, Fundación IMDEA Energía, Impact Hydrogen BV, Institut de Recherches en Énergie Solaire et Énergies Nouvelles, Noordwes-Universiteit, STAM SRL, Strathmore University, Teknologie Solutions Limited

https://just-green-afrh2ica.eu/

PROJECT AND GENERAL OBJECTIVES

JUST GREEN AFRH2ICA aims to develop a green hydrogen just transition roadmap that would make African–European transition pathways to H_2 synergic and sustainable (from environmental and social points of view), while avoiding any new EU hydrogen colonisation of Africa and promoting a mutually beneficial collaboration between the two continents for the development of independent and collaborative hydrogen economies, research and development ecosystems and value chains. To do so, JUST GREEN AFRH2ICA has involved key partners from the EU and African Union (AU) sides at the association (African Hydrogen Partnership and Hydrogen Europe), academia, research and technology organisation and policymaking levels. JUST GREEN AFRH2ICA aims to be a stepping stone to a collaborative hydrogen roadmap that, based on the analysis of different AU green H_2 scenarios at the socioeconomic-technical level via partners' tools (also assessing local resources – renewable energy sources and water are the key ones for green hydrogen production), will also drive future investments and policies and the set-up of local manufacturing lines.

NON-QUANTITATIVE OBJECTIVES

- Support the mutual benefit collaboration between Africa and Europe on green hydrogen initiatives.
- Promote a just green hydrogen transition on both continents.
- Stimulate the sharing of know-how between the continents.
- Identify the most interesting African countries for investing in green hydrogen, looking at both domestic markets and export to Europe.

PROGRESS AND MAIN ACHIEVEMENTS

- Assessment of the green hydrogen potential of African countries using a multisectoral approach.
- Identification of the use cases to be modelled as archetypes of potential African hydrogen offtakers.
- Definition (partly based on stakeholders' insights) of the hydrogen hub approach inspired by and in comparison with the European hydrogen valley approach.
- Detailed assessment of AU–EU green hydrogen policies and points of interaction.
- Analysis of existing natural gas infrastructure's potential to be enriched by hydrogen to transport it to the EU.
- Development and enhancement of partners' models to be adapted to the African context and data availability (e.g. innovative water modelling/assessment approaches).
- Interaction with stakeholders through surveys and at events to collect inputs to project actions in work packages 1–3.
- Launch of the e-learning platform and of the first package of training materials.
- Organisation of a training workshop in Nairobi in concomitance with a large EU–AU workshop.
- Participation in > 10 events, delivery of three speeches at international conferences, organisation of five stakeholders' workshops, running of a robust social media campaign and release of the first project videos.

FUTURE STEPS AND PLANS

- Modelling of the project use cases to collect information and results to drive the drafting of the project's joint EU–AU roadmaps (research and development, financing, manufacturing and electrolyser installation).
- Set-up of the second e-learning package.
- Organisation of further stakeholders' workshops and trainings.
- Organisation of a final event to present the project roadmaps and findings.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objectives	Modelling tools from the consortium updated	number	5	N/A	
	Number of trainees	number	> 200	60	
	Approval of the project roadmaps	%	> 70 %	N/A	
	Modelling AU green H_2 scenarios using unique consortium tools	number of use cases	4	N/A	
	Number of users of the JUST GREEN AFRH2ICA matchmaking/stakeholder platform	number of registered users	> 150	N/A	
	Number of AU countries' policies analysed	number	10	25	✓
	Stakeholders' interaction – number of stakeholders engaged in activities	number	At least 25 stakeholders always present and active in planned stakeholder-driven activities	> 25	✓

Clean Hydrogen Partnership
Co-funded by the European Union

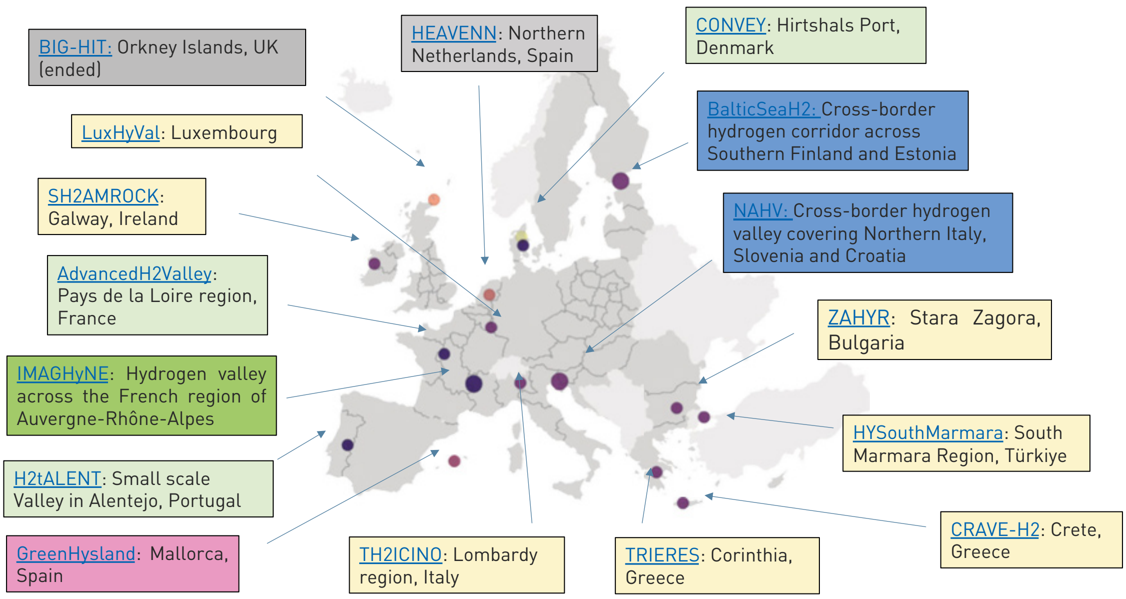
VI. PILLAR 6 – HYDROGEN VALLEYS

OBJECTIVES: Hydrogen valleys strive to establish comprehensive regional green systems by integrating the entire hydrogen value chain, including production, storage, distribution and end-use. The focus is on system efficiency and resilience, market creation, suitable regulation and standards development and knowledge management.

The call topics distinguish two types of valley: large valleys and small valleys. In 2023, the Clean Hydrogen JU selected 7 small and 2 large hydrogen valley projects for funding (total budget EUR 105.4 million) following its first call for proposals (2022). Four projects were awarded funding from the 2023 call, one of which is a large valley. An additional hydrogen valley from the 2023 call has started preparation of a GA.

The Clean Hydrogen JU has funded 16 hydrogen valley projects in 16 European countries (including BIG HIT that ended in 2022) at different scales, with hydrogen production mainly via electrolysis and diverse end-uses (Figure 28).

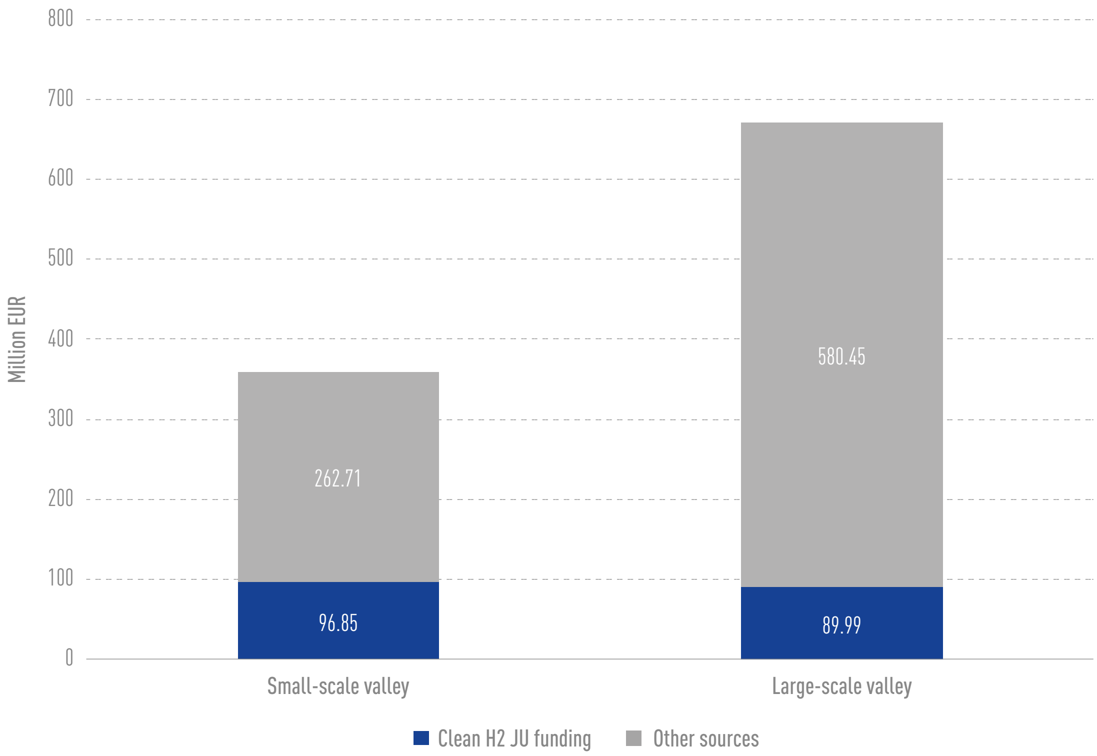
Figure 45: Hydrogen valleys supported by the Clean Hydrogen Partnership



Source: Clean Hydrogen JU.

OPERATIONAL BUDGET: As can be observed from Figure 28, the JU funding percentage for hydrogen valley projects is low, with the four large valleys being funded on average at 13 % and the 12 small valleys on average at 27 %. There is a large variation in funding rates for individual projects, ranging from 7 % (NAHV) to 75 % (BalticSeaH2). All projects rely heavily on external (public-private) sources of funding, often from multiple sources.

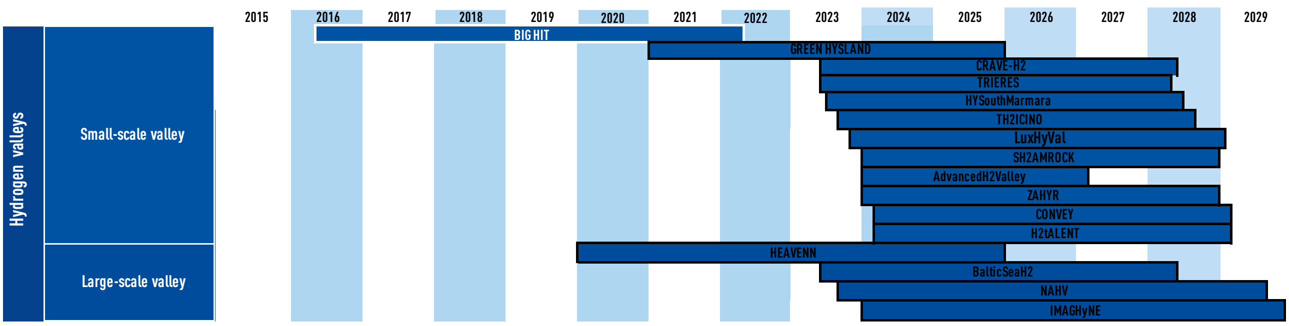
Figure 46: Funding for pillar 6 projects from 2008 to date



Source: Clean Hydrogen JU.

PROJECTS IN BRIEF: Fifteen projects are contributing to this research area, as shown in Figure 47.

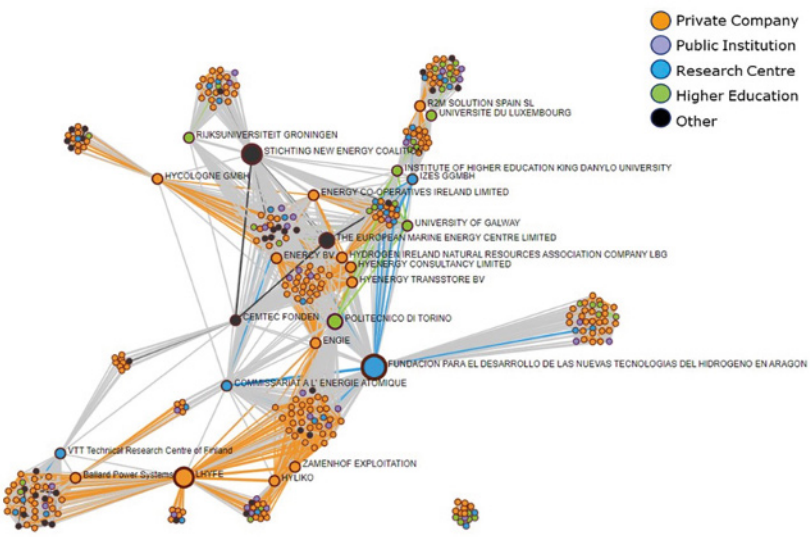
Figure 47: Project timelines for pillar 6 – hydrogen valleys



Source: Clean Hydrogen JU.

Figure 48 is a plot produced using TIM. This plot shows the connections between partners present in the projects in Pillar 6. The size of the node represents the number of projects a partner is involved in, whilst the thickness of the links represents the number of projects in common between the linked partners. For clarity, only the partners involved in the largest numbers of projects are named. There are connections between projects through one or more entities, but there is one project (HYSOUTHMARMARA) that is not connected to any of the other clusters. The top participants are all research organisations. The Fundacion para el desarrollo de las nuevas tecnologias del hidrogeno is involved in 5 projects.

Figure 48: TIM plot showing the participants in the 15 projects in pillar 6



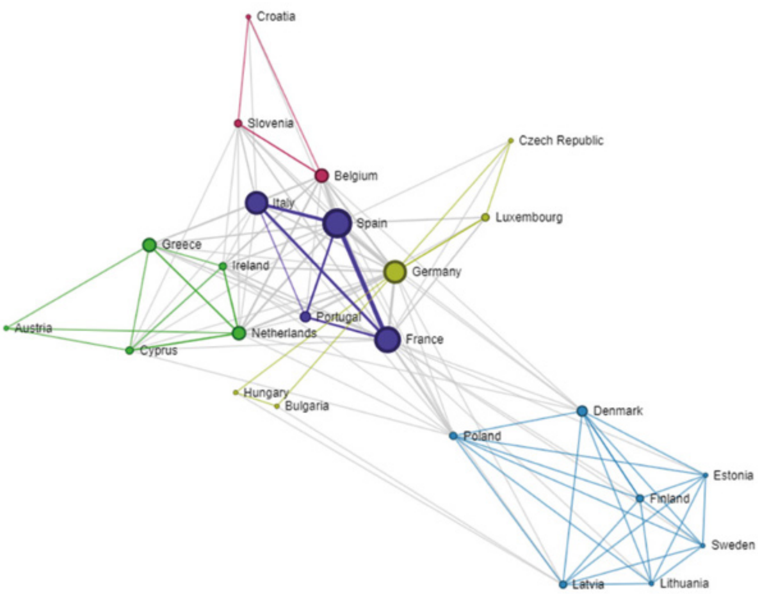
Top Participants

Participant	Number of Projects
FUNDACION PARA EL DESARROLLO DE LAS NUEVAS TECNOLOGIAS DEL HIDROGENO EN ARAGON	5
LHYFE	4
STICHTING NEW ENERGY COALITION	4
POLITECNICO DI TORINO	3
THE EUROPEAN MARINE ENERGY CENTRE LIMITED	3

Source: TIM, JRC, 2024.

Figure 49 shows the EU Member States participating in the projects assessed in Pillar 6. The size of the node represents the number of projects that has at least one participating organisation from that country. The thickness of the links between the nodes is proportional to the number of projects those countries have in common. The most significant country is Spain, which is involved in 9 hydrogen valley projects, closely followed by Germany, Italy and France.

Figure 49: TIM plot showing EU country participation in pillar 6 projects



Member State	Number of Projects
Spain	9
Germany	8
Italy	7
France	6
Denmark	4
Netherlands	4
Belgium	4
Greece	4
Portugal	3
Ireland	3

Source: TIM, JRC, 2024.

Large-scale H2 valleys

HEAVENN is implementing several hydrogen-related infrastructure projects across four clusters in the northern Netherlands. The project studied the potential for hydrogen in heavy-duty transportation in the region.

BalticSeaH2 ambitiously aims at creating the first cross-border hydrogen valley within 5 years. It will involve southern Finland and Estonia as the main valley, which will generate an interregional hydrogen economy since this area has the potential to produce more renewable energy than it can consume. Furthermore, the area is already supported by existing integrated infrastructure such as an electricity grid, a natural gas pipeline and active marine traffic that will facilitate interregional collaboration.

NAHV involves cross-border relationships, specifically between three countries in the northern Adriatic: Croatia, Italy and Slovenia. The project plans to decarbonise three sectors with six test cases each: industry with 52 % of the hydrogen produced, energy with 20 % and the transport sector with the remaining 28 %.

IMAGHYNE is intended to expand investment in transport applications in the Auvergne-Rhône-Alpes region of France, with the deployment of a range of on-road and off-road FC vehicles for public and private fleets. The salt cavern tested in the HYPSTER project will be used to store up to 44 tonnes of hydrogen.

Small-scale H2 valleys

GREEN HYSLAND will establish a green hydrogen ecosystem on Mallorca, in the Balearic Islands, featuring the utilisation of green hydrogen to power FC buses, light-duty vehicles and dedicated HRSs.

HYSOUTHMARMARA, located in the South Marmara region of Türkiye, has a capacity of nearly 3 GW of renewable electricity. The region has the ambitious vision of phasing out use of fossil fuels completely by 2053. Türkiye plans to investigate the possibility of producing green ammonia and methanol[124].

CRAVE-H2 is based on the Greek island of Crete and is aimed at the production and storage of hydrogen; its distribution to a filling station; and its use in power plants, industry and road and marine transportation.

LuxHyVal is a flagship project for developing a hydrogen economy in Luxembourg. The entire value chain will be addressed, from production to utilisation, aiming at integrating already existing infrastructure.

TH2ICINO (Italy) aims to develop and validate master planning tool software by integrating six replicable use cases involving the whole hydrogen value chain in order to support the development of micro hydrogen economies at local and regional level.

TRIĒRĒS is being implemented in Greece as a small-scale valley, but it aims to become the flagship hydrogen valley in the south-eastern Mediterranean area. The project aims at producing, storing, transporting and distributing 2 410 tonnes/year of green hydrogen to end-users in road and maritime mobility, industry and energy. The electrolyser is funded by the JU through the EPHYRA project.

SH2AMROCK plans to expand the first hydrogen valley in Ireland, the Galway Hydrogen Hub, focusing on mobility rather than industry. It claims to be a replication of HEAVENN, although it is rather different in terms of the potential end-users.

ZAHYR will be the first hydrogen valley in Bulgaria, located in the east, near Stara Zagora. The area is suffering from low air quality due to emissions from industry and traffic, and the project will therefore focus on mobility applications.

ADVANCEDH2VALLEY, in the Pays de la Loire region, will be the third valley in France, focusing on transport applications. It is set to deploy 29 waterborne and land vehicles (light-duty vehicles, HDVs, tractors for ports and a ferry). It also plans to educate at least 300 students on hydrogen.

124 https://www.b2match.com/e/wind-energy-international-matchmaking-event/opportunities/UGFydGljaXBhdGlvbk9wcG9ydHVuaXR5Ojk1Njg0

H2TALENT, in Portugal, will work towards achieving its goals by enabling the use of green hydrogen in a range of end-use sectors, from industrial (refinery and plasterboard) and mobility (buses and bin lorries) to residential. It is also set to help decarbonise the Port of Sines.

CONVEY, located in the Port of Hirtshals in northern Denmark, will provide hydrogen for logistics in the port and for the food processing industry. It is notable that the oxygen produced will be utilised by aquaculture.

PROJECT FACTSHEETS PILLAR 6

Large-scale H2 valleys

HEAVENN
BalticSeaH2
NAHV
IMAGHYNE

Small-scale H2 valleys

GREEN HYSLAND
HYSOUTHMARMARA
LuxHyVal
TH2ICINO
TRIĒRĒS
SH2AMROCK

HEAVENN

HYDROGEN ENERGY APPLICATIONS FOR VALLEY ENVIRONMENTS IN NORTHERN NETHERLANDS

Project ID	875090
PRR 2024	Pillar 6 – H_2 valleys
Call topic	FCH-03-1-2019: H_2 valley
Project total costs	EUR 99 720 599.49
Clean H_2 JU max. contribution	EUR 20 000 000.00
Project period	1.1.2020–31.12.2025
Coordinator	Stichting New Energy Coalition, Netherlands
Beneficiaries	Bytesnet Groningen BV, Cemtec Fonden, Emmtec Services BV, Enercy BV, Energie Beheer Nederland BV, Engie Energie Nederland NV, European Marine Energy Centre Ltd, European Research Institute for Gas and Energy Innovation, EWE GASSPEICHER GmbH, Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón, Gemeente Emmen, Gemeente Groningen, Gemeente Hoogeveen, Green Planet Real Estate BV, Groningen Seaports NV, H2Tec BV, Hinicio, HyCC BV, Hydrogen Ireland Natural Resources Association Company LBG, HyEnergy Consultancy Limited, HyEnergy TransStore BV, Lenten Scheepvaart BV, Logan Energy Limited, Nederlandse Aardolie Maatschappij BV, Nederlandse Particuliere Rijnvaart-Centrale Cooperatie UA, Nobian Industrial Chemicals BV, NV Nederlandse Gasunie, PitPoint. Crew BV, PitPoint.Pro BV, Qbuzz BV, Rijksuniversiteit Groningen, Shell Nederland Verkoopmaatschappij BV, TotalEnergies Gas Mobility BV, TotalEnergies Marketing Nederland NV, UVO Vervoer BV

https://heavenn.org/

PROJECT AND GENERAL OBJECTIVES

Heavenn is a large-scale demonstration project bringing together core elements – production, distribution, storage and local end use of H_2 – into a fully integrated and functioning hydrogen valley that can serve as a blueprint for replication across Europe and beyond. The main goal is to make use of green H_2 across the entire value chain, while developing replicable business models for wide-scale commercial deployment of H_2 across the entire regional energy system.

NON-QUANTITATIVE OBJECTIVES

- Safety issues will be covered by permit-issuing procedures.

PROGRESS AND MAIN ACHIEVEMENTS

- The salt barge hull is actively sailing in the Netherlands. It uses a container swap solution to refuel on hydrogen. Salt cavern testing is ongoing and has been successful so far.
- A large proportion of the mobility applications (i.e. vehicles) have been ordered or purchased and will be delivered this year.
- Data collection is being taken over by a new partner, which will start collecting data as soon as they become available.
- Gasunie successfully conducted the first static tests and demonstrated that H_2 can be safely stored in salt caverns. The connection specification study was completed, covering various options. This study considered different market situations/developments and the scalability of the design, resulting in a plot plan and capacity range definition. The designs and site layout plans of subsequent H_2 caverns are in progress.
- The Eemshaven area is in the process of matchmaking for the pipeline, looking for customers and purchase agreements. The HyCC factory is on the way to a financial investment decision (FID). The Hydrogen Hub has requested a final co-financing subsidy and will then take its FID. The hydrogen refuelling station here is operational and used by the partner UVO.
- In Hoogeveen, the construction of houses powered by hydrogen has begun. Research is ongoing to find the right solution to fuel the data centre, and the size and type of fuel cell required.
- The Emmen EMMHY pipeline is in place. Emmtec is ready to start using hydrogen, but no contract is in place.

FUTURE STEPS AND PLANS

- The critical assessment of deliverables is planned. Since the grant agreement, a number of changes have occurred. The tasks and deliverables will be critically reassessed and updated if necessary.
- Partners are still waiting for co-funding. If co-funding is secured, they will accelerate all actions. The consortium is also waiting on a definitive project extension so that they can take a FID.
- Much effort will be put into connecting the various hydrogen valley projects, sharing experiences and lessons learnt, creating synergies and thus strengthening each other.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives and AWP 2019	Cluster 1: salt barge and refuelling	t H_2 per year	80	
	Cluster 2: salt cavern storage	t H_2 per year	–	
	Cluster 2: heating of buildings for Gemeente Hoogeveen, Bytesnet Groningen and others	t H_2 per year	155	
	Cluster 3: Emmen	t H_2 per year	–	
	Cluster 4: mobility	t H_2 per year	260	
	WP 5: impact analysis and business models	t H_2 per year	–	
	WP 6: research aiming towards future H_2 roll-out	t H_2 per year	80	

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BALTICSEAH2

CROSS-BORDER HYDROGEN VALLEY AROUND THE BALTIC SEA

Project ID	101112047
PRR 2024	Pillar 6 – H_2 valleys
Call topic	HORIZON-JTI-CLEANH2-2022-06-01: Hydrogen valleys (large-scale)
Project total costs	EUR 33 235 406.25
Clean H_2 JU max. contribution	EUR 24 998 830.00
Project period	1.6.2023–31.5.2028
Coordinator	CLIC Innovation Oy, Finland
Beneficiaries	Aalto-korkeakoulusäätiö SR, ABB Oy, Ballard Power Systems Europe A/S, Baltic Innovation Agency OÜ, Borealis Polymers Oy, Convion Oy, Cybernetica AS, Elcogen Oy, Elomatic Consulting & Engineering Oy, Energiforsk AB, Energy Cluster Denmark, Energy Valley, Flexens Oy AB, Gasgrid Finland Oy, Green North Energy Oy, Helen Oy, Iwen Energy Institute gGmbH, Keemilise ja Bioloogilise Füüsika Instituut, Lhyfe, MTÜ Viru Vesinik, Neste Oyj, OÜ Hendrikson & Ko, P2X Solutions Oy, PowerUP Fuel Cells OÜ, Research Institutes of Sweden AB, Rīgas brīvostas pārvalde, Rønne Havn A/S, Skyborn Renewables Sweden AB, Solarstone Infra OÜ, Stowarzyszenie Dolnośląska Dolina Wodorowa, Sustainable Business and Technology Development Sihtasutus, Tallinna Linn, Teknologian tutkimuskeskus VTT Oy, Uppsala Universitet, Vandenilio energetikos asociacija, Vantaan Energia Oy, Viking Line Abp, Wärtsilä Finland Oy, Yara Suomi Oy, Zaļo un Viedo Tehnoloģiju Klasteris

https://balticseah2valley.eu/

PROJECT AND GENERAL OBJECTIVES

BalticSeaH2 aims to build the first significant, cross-border hydrogen valley in Europe. The goal is to create an integrated hydrogen economy around the Baltic Sea to enable energy self-sufficiency and minimise carbon emissions from various industries. Combining local areas into a broader valley will help create a genuinely integrated, interregional hydrogen economy.

The area between Estonia and Finland is an optimal location for a cross-border hydrogen market. The necessary infrastructure – natural gas pipelines, electricity grids and active marine traffic – already exists in the Gulf of Finland. Additional hydrogen infrastructure is already planned: the Nordic–Baltic Hydrogen Corridor, the Baltic Sea Hydrogen Collector and the Nordic Hydrogen Route will enable the strong growth of the hydrogen economy and hydrogen markets in the Baltic Sea region.

Over 20 demonstration cases and over 10 investment cases will showcase the diverse applications of hydrogen across multiple sectors. The production potential for hydrogen will reach 100 000 t annually by the end of the project. The hydrogen and its derivatives can be utilised or sold by the industries brought together by the project.

NON-QUANTITATIVE OBJECTIVES

BalticSeaH2 will pioneer a large-scale interregional hydrogen valley, as there is no established framework to guide the process for developing a cross-border hydrogen economy including the necessary financial, legal, environmental and technical pre-requisites to develop such a market. BalticSeaH2 will plan, design and implement hydrogen technologies along the entire hydrogen value chain (production, distribution, and consumption), support the scale-up of the project results to countries in the Baltic Sea region, optimise the cost and energy efficiency of the established technical solutions, increase societal awareness and acceptance of hydrogen technologies and the hydrogen economy, and develop an integrated market model that maximises system efficiency and enables the establishment of an interregional hydrogen economy in the region.

PROGRESS AND MAIN ACHIEVEMENTS

The project started in June 2023. The project structures, online presence and communication channels have been set up and most tasks have begun. The consortium has participated in events aiming to raise awareness of the valley. The development of the use cases and investment cases has started, but some of the cases are still confidential because the final investment decisions (FIDs) have not been published yet. Use cases, investment cases and other results will be actively communicated with all quadruple helix stakeholders as progress is made.

FUTURE STEPS AND PLANS

BalticSeaH2 intends to create a large-scale hydrogen valley between Estonia and Finland. In addition, there are replication valleys in Denmark, Germany, Latvia, Lithuania, Norway, Poland and Sweden. Replication valleys are closely involved in the BalticSeaH2 project activities already, but the project will create a replication toolkit and best-practice handbook to disseminate knowledge and lessons learnt regarding building a hydrogen economy involving the whole hydrogen value chain.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objectives	Number of end-use opportunities served by the use cases with FIDs	number	20	4	
	Tonnes of new renewable H_2 produced in use cases with FIDs	t H_2/year	60 000	0	
	Number of sector couplings in the use cases with FIDs	number	15	6	
	Additional funding raised for boosting use cases	M€	2 500	90	
	Number of new H_2 valleys boosted	number	10	4	
	Number of interregional strategic cooperation actions	number	15	3	

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NAHV

NORTH ADRIATIC HYDROGEN VALLEY

Project ID	101111927
PRR 2024	Pillar 6 – H_2 valleys
Call topic	HORIZON-JTI-CLEANH2-2022-06-01: Hydrogen valleys (large-scale)
Project total costs	EUR 345 326 582.18
Clean H_2 JU max. contribution	EUR 24 996 826.69
Project period	1.9.2023–31.8.2029
Coordinator	Holding Slovenske elektrarne d.o.o., Slovenia
Beneficiaries	Acciaierie Bertoli Safau SpA, AcegasApsAmga SpA, ACTIVE SOLERA jednostavno društvo s ograničenom odgovornošću za usluge, Adriatic Croatia International Club, za djelatnost marina d.d., Alpacem Cement, d.d., Area di Ricerca Scientifica e Tecnologica di Trieste, Azienda Provinciale Trasporti SpA, CTS H2 SRL, Danieli Centro combustion SpA, Dilj industrija građevinskog materijala d.o.o., DOK-ING Indeloop d.o.o. za proizvodnju elektricne energije i gospodarenje otpadom, Ecubes Tehnologije d.o.o., Faber Industrie SpA, Ferriere Nord SpA, Fondazione Bruno Kessler, Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón, Gitone Kvarner d.o.o., HSE Invest družba za inženiring in izgradnjo energetskih objektov d.o.o., Maritime Center of Excellence d.o.o., META, META circularity, svetovanje in inovacije d.o.o., META Group SRL, Ministarstvo gospodarstva i održivog razvoja, Ministrstvo za infrastrukturo, Regione Autonoma Friuli Venezia Giulia, Snam SpA, Steklarna Hrastnik, družba za proizvodnjo steklenih izdelkov d.o.o., Sveučilište u Rijeci, Sveučilište u Rijeci Tehnički Fakultet, Sveučiliste u Splitu Fakultet elektrotehnike, strojarstva i brodogradnje, Sveuciliste u Zagrebu Fakultet strojarstva i brodogradnje, termoelektrarna sostanj d.o.o., Trasporto Pubblico Locale Friuli Venezia Giulia SCARL, Trieste Trasporti SpA, Università degli Studi di Trieste, Univerza v Ljubljani

https://www.nahv.eu/

PROJECT AND GENERAL OBJECTIVES

The North Adriatic Hydrogen Valley (NAHV), a Horizon Europe project supported by the Clean Hydrogen Partnership, is a response to an initiative launched by key members of industry in the target region, who requested coordinated action to develop a cross-regional innovation ecosystem at the first Hydrogen Ecosystem North Adriatic Conference, held in Nova Gorica in the autumn of 2021. The initiative builds on the agreement signed in early 2022 by representatives of the Slovenian Ministry of Infrastructure, the Croatian Ministry of Economy and Sustainable Development, and the Friuli Venezia Giulia (FVG) autonomous region in Italy to jointly contribute to the European Green Deal and European hydrogen strategy goals. On 14 March 2022, the Slovenian State Secretary of the Ministry of Infrastructure, the Croatian State Secretary of the Ministry of Economy and Sustainable Development, and the President of the FVG autonomous region signed a joint letter of intent in which they recognised the importance of regional cooperation and a cross-border hydrogen valley in boosting the energy transition and promoting sectoral integration between transport, hard-to-abate industries and end users in an integrated ecosystem. With this letter of intent, the three signatories committed to implementing a common innovation agenda and cooperation projects to accelerate the deployment of hydrogen-based solutions, thus strengthening local hydrogen ecosystems and building interregional value chains. The European hydrogen backbone considers the three territories that are part of the NAHV project – Croatia, FVG (Italy) and Slovenia – as one part of the larger pan-European hydrogen supply and import corridors, which will connect industrial clusters, ports and hydrogen valleys to regions with abundant hydrogen supply.

To fulfil these objectives, the NAHV project involves a well-rooted partnership of 37 organisations (of which two are part of Hydrogen Europe and three are part of Hydrogen Europe Research), covering the transnational central European area of three territories – Croatia, Slovenia and the FVG region – demonstrating the cross-border integration of hydrogen production, distribution and consumption, and building capacities for annual hydrogen production of over 5 000 t, of which over 20 % is expected to be exchanged within the area of the NAHV project.

The project will activate 17 test bed applications in their ecosystems, clustered into three main pillars: hard-to-abate industries, the energy sector and the transport sector. These will act as real-life cases for piloting global hydrogen markets, moving from technology readiness level 6 at the beginning to level 8 by the end of the project.

Four fuel cell applications in the energy and transport sectors will be demonstrated. Test beds will then be scaled up to the industrial level as a replicable model, contributing to the decarbonisation of the three territories by harnessing renewables to improve system resilience, security of supply and energy independence.

NON-QUANTITATIVE OBJECTIVES

The NAHV project is the establishment of a NAHV association as an Association Internationale Sans but Lucratif (AISBL). Under the coordination of Area di Ricerca Scientifica e Tecnologica di Trieste, the first steps towards the AISBL constitution have been taken. Partners will work to (i) prepare all the formal documentation for the incorporation of the AISBL, (ii) define the business plan and organisational model and (iii) define the financial needs and source for covering those costs. The NAHV AISBL will be supported by the three countries involved, and it will become the governing body of the NAHV ecosystem, going far beyond the NAHV project.

FUTURE STEPS AND PLANS

In the coming months, the main activities of the project NAHV will be identifying co-funds at the European and national levels and preparing all spatial and technical documentation needed to start hydrogen production installation at various locations in the valley.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	CO_2 savings	t/year CO_2eq	32 000	
	Cross-border hydrogen valley	-	17 renewable H_2 supply chain test beds in hard-to-abate, energy and transport sectors	
	Education and training	-	7 000 future professionals and experts trained, including through vocational training programmes and the creation of a macroregional competence centre for hydrogen research and education and the training and educational mentoring programme H2Student	
	Hydrogen production distributed in Croatia, Italy and Slovenia	t/year	6 000 (indicatively 50 % in industry, 30 % in the transport sector and 20 % in the energy sector)	

IMAGHYNE

IMAGHYNE: INVESTMENT TO MAXIMISE THE AMBITION FOR GREEN HYDROGEN IN EUROPE

Project ID	101137586
PRR 2024	Pillar 6 – H_2 valleys
Call topic	HORIZON-JTI-CLEANH2-2023-06-01: Large-scale hydrogen valley
Project total costs	EUR 192 164 346.25
Clean H_2 JU max. contribution	EUR 19 996 911.75
Project period	1.1.2024–31.12.2029
Coordinator	Région Auvergne-Rhône-Alpes, France
Beneficiaries	Aéroports de Lyon, ANA Aeroportos de Portugal, SA, Arkema France SA, Association Cara, Atawey, Axelera – Association Chimie-Environnement Lyon et Rhône-Alpes, Bontaz Centre, Bouygues Energies & Services, Commissariat à l'énergie atomique et aux énergies alternatives, Communauté de Communes Faucigny-Glières, Commune de Bonneville, Compagnie Nationale du Rhône SA, Engie Energie Services, ERM France, Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón, G. Jacquemmoz et Fils, GRDF SA, Green Corp Konnection, GRTgaz, Hyliko, Hympulsion SAS, Hynamics, Imagine..., Institut national de l'environnement industriel et des risques, Keolis, Lhyfe, Lhyfe Production 3, Manufacture Française des Pneumatiques Michelin, Nomads Foundation, Politecnico di Torino, PolyTechnyl SAS, SAS PUM, SATA Group, Societé Rhodanienne des cars Ginhoux, Storengy France, Storengy SAS, Symbio France, Syndicat Mixte des 4 Communautés de Communes, Technologies énergies nouvelles énergies renouvelables, Rhône-Alpes, Drôme, Isère, Savoie et Haute-Savoie, Transports LTR-Vialon, VINCI Airports, Watea, Zamenhof Exploitation

www.imaghyne.eu

PROJECT AND GENERAL OBJECTIVES

Imaghyne will dramatically accelerate the deployment of hydrogen technologies in Auvergne-Rhône-Alpes. The ambition is to activate a long-lasting hydrogen economy that is fully integrated into the wider energy system and addresses the needs of high-emitting sectors. Imaghyne will be deeply connected to European initiatives to further expand and accelerate synergies and enable quicker uptake of hydrogen innovations in Europe and beyond. In addition, Imaghyne will gather key public and private stakeholders, foster investments along the entire hydrogen value chain and create the conditions to achieve a pan-European hydrogen economy at scale. To achieve this main target, the project partners created the following list of objectives aligned with the call criteria.

- Deploy 57 MW of electrolysis capacity to produce 8 000 t/year of low-carbon and renewable hydrogen.
- Implement a flexible hydrogen supply chain securing local ecosystems by deploying 20 high-capacity tube trailers and a multitonne hydrogen storage system in an underground salt cavern.
- Deploy 13 multimodal hydrogen refuelling stations that will contribute to the cohesion, efficiency and sustainability of the trans-European transport network and ensure there is a clear pathway to decarbonising public transport fleets.
- Deploy 199 on-road fuel cell vehicles (of various types) from public and private fleets.
- Deploy 63 off-road fuel cell vehicles and stationary equipment to decarbonise agricultural, mountainous and airport hubs; this will include the replacement of three emergency diesel generators with a 4 MW hydrogen stationary fuel cell for power generation to secure airport operations.

To create a real ecosystem, the project gathers a multiplicity of partners, including the production side, storage side and end-use side.

NON-QUANTITATIVE OBJECTIVES

- Strengthen the robustness of the overall energy and hydrogen supply chain by integrating a flexible industrial player into the ecosystem.
- Design an efficient, pipeline-based, multiuser hydrogen system and provide evidence to help determine the optimum hydrogen transport and storage technology choice(s) for wider roll-outs.
- Prepare for additional large-scale deployment as part of the valley extension and its replication in Europe and beyond.

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PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	CO_2 emissions avoided resulting in the off-road mobility and energy-related actions	kt	6.5	
	Amount of hydrogen injected into and extracted from the salt cavern during the project	t	300	
	Off-road vehicles deployed during the project	number	Three farm tractors, five snow groomers, 61 GSE engines	
	CO_2 emissions avoided resulting in the industry-related actions developed	kt CO_2eq	150	
	Stationary fuel cells deployed	number	1	
	Monitored operational period for each type of vehicle	months	> 24	
	Tonnes of low-carbon and renewable hydrogen used in Arkema's process	t H_2	16 000	
	Average hours of operation per off-road vehicle per year	h/year	Farm tractors: 600 h/year; snow groomers: 1 300 h/year; average GSE: 540 h/year	
	Monitored operational period for off-road vehicles	months	> 24	
	CO_2 emissions avoided resulting in the mobility-related actions	kt	14.2	
	Electrolysis capacity deployed	MW	57	
	Underground storage capacity of hydrogen in salt cavern available for commercial exploitation	t	44	
	Average availability rate of the electrolyser	%	80–90	
	Evaluation of H_2 deployment scenario (technical, economic, environmental, societal and safety/risk criteria)	number of scenarios analysed	2	
	40-ft tube trailers deployed	number	20	
	Total hours of operation across the entire off-road fleet	hours, days	Farm tractors: 7 200 hours, 1 000 days; snow groomers: 25 000 hours, 1 000 days; total GSE: 130 000 hours, 5 500 days	
	Regions/organisations targeted by replicability actions	number	5	
	Length of additional pipeline to be deployed secured by feasibility studies	km	40	
	Years of operation of the electrolysers	year	2	
	Amount of renewable hydrogen produced	t/year	4 000	
	Hydrogen distribution capacity available	t/day	10	
	Average distance driven per vehicle per year	km/year	Coaches/buses: > 40 000 km/year: light-duty vehicles > 35 000 km/year; trucks 100 000 km/year	
	Distance driven across the entire fleet	km	Buses/coaches: > 3 000 000 km: light-duty vehicles: 28 000 000 km; trucks: 7 000 000 km	
	Vehicles deployed	number	17 coaches/buses; 164 light-duty vehicles; 18 heavy-duty vehicles	
	Hydrogen refuelling stations deployed	number	13	
	Amount of low-carbon plus renewable hydrogen produced	t/year	8 000	
	Length of small-scale pipeline deployed	km	0.8–2.3	
	Amount of hydrogen delivered by tube trailers within the project	t	2 500	

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GREEN HYSLAND

GREEN HYSLAND – DEPLOYMENT OF A H_2 ECOSYSTEM ON THE ISLAND OF MALLORCA

GREEN HYSLAND

Project ID	101007201
PRR 2024	Pillar 6 – H_2 valleys
Call topic	FCH-03-2-2020: Decarbonising islands using renewable energies and hydrogen – H_2 islands
Project total costs	EUR 23 717 171.38
Clean H_2 JU max. contribution	EUR 9 999 999.50
Project period	1.1.2021–31.12.2025
Coordinator	Enagás Renovable SL, Spain
Beneficiaries	Acciona Generación Renovable SA, Agência Regional da Energia e Ambiente da Região Autónoma da Madeira, Ajuntament de Lloseta, Asociación Chilena de Hidrógeno, Asociación Española del Hidrógeno, Asociación Ibérica de Gas Natural, Hidrógeno y Gas Renovable para la Movilidad, Association Marocaine pour l'Hydrogène et le Développement Durable, Autoridad Portuaria de Baleares, Baleària Eurolíneas Marítimas SA, Calvera Hydrogen SA, Centro Nacional de Experimentación de Tecnologías de Hidrógeno y Pilas de Combustible Consorcio, Commissariat à l'énergie atomique et aux énergies alternatives, Consultoria Tecnica Naval Valenciana SL, Diktyo Aeiforikon Nison Toy Aigaiouae, Empresa Municipal de Transports Urbans de Palma de Mallorca SA, Enagás SA, Enercy BV, Energy Co-operatives Ireland Ltd, European Marine Energy Centre Ltd, Fédération européenne des agences et des régions pour l'énergie et l'environnement, Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón, Gemeente Ameland, HyCologne GmbH, HyEnergy Consultancy Limited, HyEnergy TransStore BV, Instituto Balear de la Energía, Power to Green Hydrogen Mallorca SL, Redexis Gas Servicios SL, Redexis Infraestructuras SL, Redexis SA, Stichting New Energy Coalition, Universidad de La Laguna, Universitat de les Illes Balears, University of Galway

https://greenhysland.eu/

PROJECT AND GENERAL OBJECTIVES

Green Hysland is developing all the infrastructure the island of Mallorca (Spain) needs to produce and consume at least 330 t of green hydrogen from newly built photovoltaic plants per year. Green hydrogen will have multiple applications on the island: a fuel supply for a fleet of fuel cell buses and other vehicles, the generation of heat and power for commercial and public buildings, a new hydrogen refuelling station (HRS) and injection into the island's gas pipeline network. The project includes the development of a roadmap to 2050 in Mallorca and activities to replicate the experiments on other islands and at other locations, including Madeira (Portugal), Tenerife (Spain), the Aran Islands (Ireland), Greek islands, Ameland (Netherlands), Chiloé Island (Chile) and Morocco. The tools developed within the project are expected to be useful for other territories, especially isolated ones, interested in replicating the project model.

NON-QUANTITATIVE OBJECTIVES

Green Hysland has been diligent in its dissemination efforts, employing various channels to reach a wide array of stakeholders. The project has organised a conference and 10 workshops to facilitate direct engagement and knowledge sharing. In addition, Green Hysland has issued 25 press releases and produced 82 non-scientific and non-peer-reviewed publications, making its work accessible to a broader audience.

In the digital sphere, the project has leveraged social media platforms extensively, with 752 posts to date, alongside the establishment of a dedicated website. Furthermore, Green Hysland has conducted communication campaigns using radio and TV. Involvement in conferences, workshops and other events, totalling 87 participations, has facilitated direct interaction and networking opportunities.

In collaboration with other EU projects, the project has engaged in 11 joint activities to amplify its reach and impact. Dissemination efforts have been tailored to engage specific audiences, with a focus on the scientific community, industry stakeholders, civil society, policymakers, media representatives, investors, customers and other interested parties. This targeted approach has yielded significant traction, ensuring the project's objectives and outcomes are effectively communicated to and understood by diverse stakeholders.

PROGRESS AND MAIN ACHIEVEMENTS

- The green H_2 production plant located on Cemex land in Lloseta has been built, and site assembly testing has been carried out.
- The engineering tasks associated with the HRS have been finalised but some issues arose with the construction, which is therefore delayed.
- The H_2 pipeline and H_2 injection point for the island's natural gas network operated by Redexis are under construction.
- The 100 kWe fuel cell that will supply electricity to the maritime station of Ports de Balears is progressing and a procurement has been launched.
- The 50 kWe combined heat and power (CHP) system to be located in the Iberostar Bahía de Palma (four-star) hotel, which will cover part of the hotel's energy demand, is progressing.
- The five hydrogen buses for the Empresa Municipal de Transports de Palma (EMT) city bus fleet have been delivered and are on-site.
- The search for car rental companies willing to incorporate H_2 vehicles into their fleets is ongoing.

In addition, important progress has been made in terms of data collection, background research and scenario production in the former and the further development of the H_2 Territories Platform. Finally, great efforts were made to disseminate information about the project through online webinars and workshops organised by the project.

FUTURE STEPS AND PLANS

- The project aims to resolve the current situation with the HRS. The work associated with the engineering of the HRS has been finalised; however, it has been identified that all the design engineering was undertaken with the EMT yard in mind, which is not available at this time owing to space limitations, so construction is delayed. Solutions are being considered and the expectation is that a solution will be found in the coming months.
- Owing to Lloseta Council's formal announcement of its intention to leave the consortium, no associated activity has been executed in relation to the CHP application in the municipal building, and other municipalities are currently being analysed. The expectation is that a solution will be found in the coming months. In addition, the consortium expects to resolve the electrolyser issues and complete the site and factory acceptance tests for the two tube trailers in the coming months.
- The work of Sebastián Barceló Vidal as General Manager of Power to Green Hydrogen Mallorca will continue during 2024, focusing on centralising all aspects related to the exploitation of the H_2 production plant and the relationship with the H_2 consumers.
- An amendment will be launched in the coming months. In it, the consortium intends to include modifications of the overall costs and due dates of deliverables and milestones, make clear OK Mobility's final decision to enter the project, make official the exit of Lloseta Council from the project consortium and explain the situation with the EMT yard and the HRS.

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GREEN HYSLAND

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
MAWP (2018–2020)	Commitment of public authorities	M€	-	6.25	
Project's own objectives	Commercial fuel-cell-based CHP system in a hotel	kWe	50	N/A	
	Fostering replication of hydrogen valley elsewhere	Replication studies on EU islands (Madeira (Portugal), Tenerife (Spain), the Aran Islands (Ireland), Greek islands and Ameland (Netherlands))	Studies on five EU islands and updated version of the Hydrogen Territories Platform	Replication tool development (from BIG-HIT) and replication studies ongoing	
	Long-term roadmap for a local and regional H_2-based economy on the island of Mallorca towards 2050	Studies	Roadmap drafted and endorsed	Studies ongoing	
	H_2 fuel cell for electricity supply for critical infrastructure at Ports de Balears	kWe	100	Call for tenders for the fuel cell launched	
	Electrolyser	MW	7.5 MW or + 300 t H_2 production per year	2.5 MW	
	Injection of H_2 into the local gas distribution grid	t H_2/year	190	Permits granted, H_2 pipeline and injection point under construction	
	10 light-duty vehicles	number	10	Discussions with potential end users ongoing	
	FC H_2 buses in Palma	number	5	5	✓

HYSOUTHMARMARA

SOUTH MARMARA HYDROGEN SHORE

Project ID	101112054
PRR 2024	Pillar 6 – H_2 valleys
Call topic	HORIZON-JTI-CLEANH2-2022-06-02: Hydrogen valleys (small-scale)
Project total costs	EUR 37 798 575.00
Clean H_2 JU max. contribution	EUR 7 999 937.50
Project period	1.7.2023–30.6.2028
Coordinator	Güney Marmara Kalkınma Ajansı, Türkiye
Beneficiaries	Alma Mater Studiorum – Università di Bologna, Bandırma Onyedi Eylül University, Enerjisa Enerji Üretim A.Ş., Eti Maden İşletmeleri Genel Mudurlugu, Hidrojen Peroksit Sanayi ve Ticaret A.Ş., Kaleseramik Çanakkale Kalebodur Seramik Sanayi A.Ş., Linde Gaz A.Ş., Sabancı Üniversitesi, Software AG, Türk–Alman Üniversitesi, Türkiye Bilimsel ve Teknolojik Araştırma Kurumu, Türkiye Enerji, Nükleer ve Maden Araştırma Kurumu, Türkiye Şişe ve Cam Fabrikaları A.Ş., Université Mohammed VI Polytechnique

https://hysouthmarmara.org/

PROJECT AND GENERAL OBJECTIVES

Türkiye's south Marmara region, currently the world's 12th-largest region in terms of installed renewable capacity, is set to boost its hydrogen economy through the HySouthMarmara valley project. The project, with a budget of EUR 37.8 million and eight work packages, aims to increase the region's hydrogen market and boost the hydrogen economy. The project will focus on green hydrogen and green fuel production, with the goal of becoming Türkiye's first carbon-neutral region by 2053.

TÜRKIYE'S HYDROGEN PROJECT OBJECTIVES ARE THE:

- creation of Türkiye's first regional hydrogen roadmap, aiming to provide recommendations for up to 2035;
- establishment of the first MW-scale green hydrogen plant, aiming to create the largest green hydrogen facility in Türkiye;
- development of a digital twin for the hydrogen production system, enabling renewable energy usage and efficient green hydrogen production;
- first use of green hydrogen in the production of hydrogen peroxide, glass, ceramic and boron chemicals;
- first investment opportunities for the green production of hydrogen derivatives such as ammonia and methanol;
- commercial production of sodium borohydride, a new boron chemical, and a new power system;
- development of Türkiye's first domestic hybrid ceramic tile kiln that can use hydrogen;
- establishment of Türkiye's first renewable energy park, Bandırma Energy Base;
- establishment of Türkiye's first hydrogen platform, the South Marmara Hydrogen Shore Platform;
- completion of Türkiye's first hydrogen training centre.

NON-QUANTITATIVE OBJECTIVES

The HySouthMarmara project aims to develop a hydrogen generation system using sodium borohydride hydrolysis, which will be used by the Disaster and Emergency Management Presidency in south Marmara. The first prototype will be installed in the presidency's logistics warehouse, demonstrating its usability in disasters such as earthquakes, landslides, major power plant failures, floods and

fires triggered by the climate crisis. This application will contribute to the social impact of hydrogen.

The project also focuses on education and skill development. By combining aspects of education, research and industry, the project will provide vocational skill training and educational programmes on hydrogen. The south Marmara region has set out a vision to become a green technologies training hub, and Güney Marmara Kalkınma Ajansı (GMKA) has increased its efforts regarding renewable-energy-related studies and projects. The renewable youth operation, financed under the EU Instrument for Pre-accession Assistance, is carried out with the partnership of GMKA and two out of three universities operating in the region. Renewable energy laboratories and applied education infrastructures are established at each university, with Bandırma Onyedi Eylül University focusing on offshore renewable technologies and green hydrogen.

The project's international dimension includes interactions, collaborations and impacts beyond national borders. Delegation visits and site visits will facilitate engagement with international partners, stakeholders and experts, allowing participants to exchange ideas, share best practices and explore opportunities for collaboration and mutual learning.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objectives	Annual green hydrogen production	t	500	N/A	
	Sodium borohydride production	t/year	10	N/A	
	Feasibility studies	number	4	1	
SRIA (2021–2027)	Installed capacity of green hydrogen plant	MW	4	N/A	

LUXHYVAL

LUXEMBOURG HYDROGEN VALLEY DELIVERING INTEGRATED FULL-CHAIN SUSTAINABLE HYDROGEN ECOSYSTEM WITH TECHNICAL, ECONOMIC, SOCIAL AND ENVIRONMENTAL BENEFITS AND SUPERIOR REPLICABILITY

Project ID	101111984
PRR 2024	Pillar 6 – H_2 valleys
Call topic	HORIZON-JTI-CLEANH2-2022-06-02: Hydrogen valleys (small-scale)
Project total costs	EUR 39 108 677.50
Clean H_2 JU max. contribution	EUR 7 999 998.64
Project period	1.11.2023–31.1.2029
Coordinator	Université du Luxembourg, Luxembourg
Beneficiaries	Autocars Sales-Lentz SA, Centre national de la recherche scientifique, CERATIZIT Luxembourg SARL, Encevo SA, Enovos Luxembourg SA, Green Power Storage Solutions SA, Institute of Higher Education King Danylo University, IZES gGmbH, Luxembourg Institute of Science and Technology, LuxEnergie SA, LuxMobility SARL, Paul Wurth SA, R2M Solution Spain SL, S.L.A. SA, SLG SA, Syndicat des tramways intercommunaux dans le canton d'Esch, Université de Bordeaux, University of New South Wales, Vysoká škola chemicko-technologická v Praze

https://www.luxhyval.eu/

PROJECT AND GENERAL OBJECTIVES

Luxhyval is launching a flagship hydrogen valley to boost the penetration of hydrogen ecosystems in Luxembourg by deploying green hydrogen initiatives across the entire value chain from local production to utilisation, including storage and distribution for a range of applications targeting industry and mobility, while also aiming to connect with existing/planned infrastructures. Several end-use applications in the mobility (i.e. private and public buses, light-duty industrial vehicles) and industry (i.e. metal and glass) are included, with the support of key commercial actors along the entire value chain and political support in line with the Luxembourg hydrogen strategy, which aims to fully decarbonise the industrial sector before 2030. Digital twinning for optimal planning and operation is delivered to support upscaling and replication, while public perception and professional upskilling deliver social benefits and equip the workforce with the competences needed. Finally, the lessons learnt and solutions are replicated in two follower valleys in central (Czechia) and eastern (Ukraine) Europe.

Luxhyval aligns its work with the vision that hydrogen is a key piece of any decarbonisation strategy, especially for energy-intensive industrial and mobility applications, enabling energy sector integration and sector coupling. Specifically, Luxhyval underpins the Luxembourg hydrogen strategy to locally generate and supply hydrogen to fulfil Luxembourg's hydrogen needs – which are currently covered by imported grey (i.e. from fossil origin) hydrogen – including a plan to replace fossil fuels with green hydrogen. This is achieved using comprehensive planning and a progressive approach to get the roadmap in motion, while providing evidence and confidence to local users, citizens and stakeholders for progressive upscaling. To achieve these overarching objectives, Luxhyval's specific objectives, with corresponding key performance indicators and targets, are defined. Specific objectives are measured quantitatively using the targeted key performance indicator metrics.

NON-QUANTITATIVE OBJECTIVES

- Social impact.
  - Increase public understanding of H_2 technologies.
  - Upskill professionals and students in terms of H_2 and provide associated jobs.
- Technological impact.
  - Fully integrate the H_2 technology ecosystem.
- Economic impact.
  - Establish a functioning green H_2 market in Luxembourg.
  - Validate the multistakeholder business model and governance.
- Environmental impact.
  - Enhance the environmental profile with zero-emission and low-noise buses.
- National impact.
  - Provide a local supply of green H_2 and energy independency.
  - Reduce dependence on imported fuels.
  - Boost the economic resources remaining in Luxembourg.
- Policy and regulatory impact.
  - Overcome bottlenecks delaying rapid H_2 market expansion.
  - Contribute to policy and regulation instruments.
  - Explore potential synergies with international markets.

PROGRESS AND MAIN ACHIEVEMENTS

- The extended feasibility study is actively progressing.
- Business models for hydrogen-integrated ecosystems, governance and agreements for operation are under investigation and evaluation; the business cases are currently being drafted.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Replication plans for hydrogen valleys in Czechia and Ukraine	-	Feasibility studies done	
	Define and execute a roadmap with upscaling and replication strategies both within Luxembourg and the Greater Region	-	Roadmap specifies share and scale of future industry and mobility use of green H_2 in Luxembourg for 2030–2050	
	Skill development	-	Three university courses and two professional training modules, with 60 professionals and 300 students trained	
	Clean hydrogen production with electrolysis	t/year	650	
	Hydrogen end use	t/year	650 (indicatively 70 % for industry and 30 % for transport)	

Clean Hydrogen Partnership
Co-funded by the European Union

TH2ICINO

TOWARDS H_2YDROGEN INTEGRATED ECONOMIES IN NORTHERN ITALY

Project ID	101112098
PRR 2024	Pillar 6 – H_2 valleys
Call topic	HORIZON-JTI-CLEANH2-2022-06-02: Hydrogen valleys (small-scale)
Project total costs	EUR 18 506 850.00
Clean H_2 JU max. contribution	EUR 7 446 920.00
Project period	1.9.2023–31.8.2027
Coordinator	RINA Consulting SpA, Italy
Beneficiaries	Air Pullmann SpA, Artelys, Centro de Investigación de Recursos y Consumos Energéticos, Comune di Busto Arsizio, Confindustria Varese, EMISIA SA – Anonimi Etairia Perivallontikon Kai Energiakon Meleton Kai Anaptixis Logismikou, Lhyfe, Società per azioni Esercizi Aeroportuali S.E.A.

http://th2icino.eu

PROJECT AND GENERAL OBJECTIVES

Th2icino spearheads the deployment of micro hydrogen economies by conceptualising and demonstrating an ecosystem. It comprises six replicable use cases:

- renewable hydrogen production,
- transport via pipelines,
- transport via tube trailers,
- hydrogen refuelling stations,
- direct refuelling from the tube,
- retrofitting of some airport ground units.

The implementation of the use cases will serve as a validation mechanism for a master planning tool, which will be designed to offer support in the techno-economic development of hydrogen valleys across the EU.

Th2icino will demonstrate a hydrogen ecosystem at the heart of Milan Malpensa Airport to foster sector coupling with the surrounding area, creating synergies between strategic pieces of the energy transition, such as airports, and hard-to-abate mobility and industries of Varese in the quest for net zero. The project's specific goals are the following:

- 500 t/year of renewable hydrogen,
- decarbonisation of at least two segments (mobility/energy),
- yearly savings equivalent to the CO_2 emissions of 1 500 cars.

NON-QUANTITATIVE OBJECTIVES

- Use a hydrogen airport as a test bed for an innovative solution.
- Establish governance of a hydrogen region.

PROGRESS AND MAIN ACHIEVEMENTS

- Preliminary hydrogen safety planning has taken place.
- Initial steps have been taken to outline the hydrogen safety-planning framework, ensuring adherence to stringent safety standards and protocols throughout the project life cycle. Safety protocols and risk assessment procedures have been developed to mitigate potential hazards associated with hydrogen production, storage and transportation.
- The modelling phase for the extended valley has begun, aiming to simulate and optimise various aspects of the hydrogen ecosystem, including production, distribution and utilisation.

FUTURE STEPS AND PLANS

- Plans are in place to commence collaboration with offtakers in March 2024.
- The focus will be on modelling ground units at the airport and developing the master planning tool to support decision-making processes related to hydrogen production, distribution and utilisation.
- Engaging with offtakers will enable the refinement of project strategies, alignment of objectives and validation of technological solutions tailored to meet end users' needs.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Emission reduction	t CO_2/year	4 400	
	Levelised cost of H_2	€/kg H_2	< 4.5	
	H_2 produced	t H_2/year	500	

TRIERES

TOWARDS THE DEVELOPMENT OF A HYDROGEN VALLEY DEMONSTRATING APPLICATIONS IN AN INTEGRATED ECOSYSTEM IN GREECE

Project ID	101112056
PRR 2024	Pillar 6 – H_2 valleys
Call topic	HORIZON-JTI-CLEANH2-2022-06-02: Hydrogen valleys (small-scale)
Project total costs	EUR 10 492 431.25
Clean H_2 JU max. contribution	EUR 7 995 825.63
Project period	1.7.2023–30.4.2028
Coordinator	Motor Oil (Hellas) Diilistiria Korinthou AE, Greece
Beneficiaries	Anónymos Etaireía Diórygas Korínthou AE, Avinoil Viomichaniki Emporiki Kai Naftiliaki Etaireia Petrelaion Monoprosopi Anonymi Etaireia, Dímos Loutrakíou – Perachóras – Agíon Theodóron, Dimosia Epicheirisi Ilektrismou Anonymi Etaireia, Dioryga Gas Monoprosopi Anonymi Etaireia Fysikou Aeriou, Ecoferry Naytiki Etaireia, Elliniki Etaireia Symmetochon Kai Periousias AE, Ethnicon Metsovion Polytechnion, FEN Research GmbH, Fulgor Monoprosopi Anonymi Eteria Elliniki Viomixania Kalodion, Hydrogen Egypt, Hydrus Anotati Synektiki Michaniki Etaireia Symvoulon Anonymi Etaireia, Idryma Technologias Kai Erevnas, Kition Ocean Port Ltd, LPC Monoprosopi Anonymi Etaireia Epexergasias Kai Emporias Lipantikon Kai Petrelaioeidon Proionton, National Centre for Scientific Research 'Demokritos', New Energy Environmental Solutions & Technologies E.E., Nova Telecommunications & Media Single Member SA, Odikes Sygkoinonies A.E., Olympia Odos Anonymi Etairia Parachorisis Gia Ton Autokinitodromo Eleusina Korinthos Patra Pyrgos Tsakona, Omospondia Ergodoton & Viomichanon Kyprou, Perifereia Peloponnisou, Piraeus Port Authority SA, Rijksuniversiteit Groningen, Stichting New Energy Coalition

https://www.trieres-h2.eu/

PROJECT AND GENERAL OBJECTIVES

Greece is focusing on sustainable innovation through the Trieres hydrogen valley, a renewable energy project based around the Motor Oil Hellas Corinth Refinery complex. The project aims to enhance local green renewable hydrogen production, transportation and end use in an integrated ecosystem. Initially small-scale, it aims to increase hydrogen production and consumption in the Balkans, south-eastern Europe and the eastern Mediterranean. The Trieres valley is a major hub of investment and talent, placing Greece on the hydrogen map for the first time thanks to its geopolitical and climate advantage.

The first Greek hydrogen valley will integrate the development, establishment and operation of the following projects.

- The first is green hydrogen production.
  - Hydrogen will be produced by an alkaline electrolyser (30 MW) with batteries for continuous operation.
  - Project will produce 2 410 t/year of green hydrogen through renewable energy systems.
- The second is green hydrogen logistics.
  - Project includes a trailer-filling terminal, a virtual pipeline and polymer pipelines connected to three consumption points.
  - Five hydrogen refuelling stations are to be in place for hydrogen distribution.
  - Hydrogen-bunkering facilities in Piraeus will service short-sea shipping vessels.
  - A compressor will be connected to the onshore natural gas pipeline of Dioriga Gas.
- The third is green hydrogen end-use applications.
  - **Maritime.** One short-sea ferry vessel will be retrofitted with a 200 kW fuel cell (FC) system.
  - **Road.** A group of FC electric vehicles will be created.
  - **Industry.** Motor Oil Hellas and LPC will consume green hydrogen to decarbonise their production processes.
  - **Energy.** Hydrogen will be injected up to 5 % volume into the national natural gas grid using the floating storage and regasification unit of Dioriga Gas.

NON-QUANTITATIVE OBJECTIVES

- Activate the hydrogen market in Greece by demonstrating the integration of various hydrogen pillars.
- Facilitate information sharing between valleys and elevate the energy market in the Balkans, south-eastern Europe and the eastern Mediterranean.
- Demonstrate the combination and integration of multiple hydrogen applications into an efficient ecosystem covering the full hydrogen value chain.
- Divide end users into three sectors: mobility, industry and energy.
- Strengthen visibility and improve public awareness of strategic actors in the hydrogen value chain and emerging hydrogen ecosystems.
- Increase public knowledge of hydrogen end uses, related technologies and applications.
- Create a replicable model so the hydrogen technologies can be reproduced and multiplied throughout small- and large-scale valleys and flagship hydrogen projects.
- Add value to the current hydrogen knowledge curve and support its take-off in the near future through state-of-the-art scientific and socioeconomic investment.

Clean Hydrogen Partnership
Co-funded by the European Union

TRIĒRĒS

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Green hydrogen consumption in the energy sector	t/year	1 000	
	Developed digital twin blueprint	number	1	
	Green hydrogen consumption in the industry sector (lubricant production and oil refinery)	t/year	1 322	
	Green hydrogen consumption in the road transport sector	t/year	≥ 22	
	FC technology for light-duty vehicles	number	≥ 2	
	Hydrogen storage and transportation	t/year	1 105	
	Public awareness events	number	20	
	Hydrogen distribution (natural gas grid compression and injection capacities)	t/h	3	
	CO_2 emission reduction	t/year	9 880	
	Hydrogen distribution (compression capacity)	kg/h	180	
	PhD summer schools	number	20	
	FC technology for ships (capacity of FCs)	kW	200	
	Unified standards and specifications for hydrogen production, storage, distribution and use	number	2	
	Low-temperature PEMFC for onshore application (FC capacity)	kWe	100	
	Training programmes for reskilling	number	10	
	Hydrogen refuelling stations	number	5	
	FC technology for HD vehicles	number	≤ 3	
	Green hydrogen supply	t/year	2 410	
	Hydrogen purification system	number	1	
	Green hydrogen consumption in the maritime transport sector	t/year	66	
	New jobs created	number	92	
	Scientific publications	number	20	
	Valley safety management plans	number	1	

Clean Hydrogen Partnership
Co-funded by the European Union

SH2AMROCK

SOURCING HYDROGEN FOR ALTERNATIVE MOBILITY, REALISING OPPORTUNITIES AND CREATING KNOW HOW IN IRELAND

SH2AMROCK
Ireland's Emerald Hydrogen Valley

Project ID	101112039
PRR 2024	Pillar 6 – H_2 valleys
Call topic	HORIZON-JTI-CLEANH2-2022-06-02: Hydrogen valleys (small-scale)
Project total costs	EUR 54 806 601.01
Clean H_2 JU max. contribution	EUR 7 582 467.22
Project period	1.1.2024–31.12.2028
Coordinator	University of Galway, Ireland
Beneficiaries	Acondicionamiento Tarrasense Associacion, BOC Gases Ireland Limited, Bord Na Mòna Powergen Limited, Chesterfield Special Cylinders Ltd, Colas Teoranta, Córas Iompair Éireann, Dublin City University, E&E MEP Studio LLC, Energy and Hydrogen Alliance, Economic and Social Research Institute LBG, Energy Co-operatives Ireland Ltd, EPRI Europe DAC, European Marine Energy Centre Ltd, Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón, Galway Aviation Services Ltd, Galway Harbour Company, Hive Hydrogen (Ireland) Limited, Hydrogen Ireland Natural Resources Association Company LBG, HyEnergy Consultancy (Europe) BV, Institute of Higher Education King Danylo University, IZES gGmbH, Kemijski inštitut, Noordwes-Universiteit, Politechnika Łódzka, Politecnico di Torino, Private Scientific Institution, Institute for Research in Environment, Civil Engineering and Energy, Skopje, Stichting New Energy Coalition

https://www.sh2amrock.eu/

PROJECT AND GENERAL OBJECTIVES

- Highlight hydrogen's role to enable deeper decarbonisation of the Irish economy through sector coupling.
- Establish Ireland's first multimodal hydrogen transport hub.
- Enable the creation of a domestic market for green hydrogen value chains.
- Ensure a fair and just transition for Ireland's isolated communities.
- Produce at least 500 t of green hydrogen per year by 2028.
- Use green hydrogen production to realise decarbonisation in multiple end-use applications.
- Create strong connections with existing European hydrogen valleys and associated initiatives to foster strong linkages in the European hydrogen sector.
- Instigate the sustainable economic growth and industrialisation of Ireland.
- Foster all-Ireland hydrogen knowledge sharing, replication activities and cross-border strategy development.
- Introduce hydrogen into the Irish energy mix to increase flexibility, security and resilience.
- Leverage lessons learnt from Sh2amrock to help develop hydrogen valley roadmaps in key replication regions in Ireland and Europe and globally.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Long-distance coaches	number	10	
	H_2 aircraft	number	1	
	H_2 injection (bitumen plant)	number	1	
	Double-decker city buses	number	3	
	Combined heat and fuel cell	number	1	
	Minibuses and vans	number	4	
	FC HGVs	number	5	
	Pipeline	bar	< 5	
	Mobile tube trailers	number	3	
	Electrolyser	MW	4	
	HRS	bar	350	

Clean Hydrogen Partnership
Co-funded by the European Union

VII. PILLAR 7 – SUPPLY CHAIN

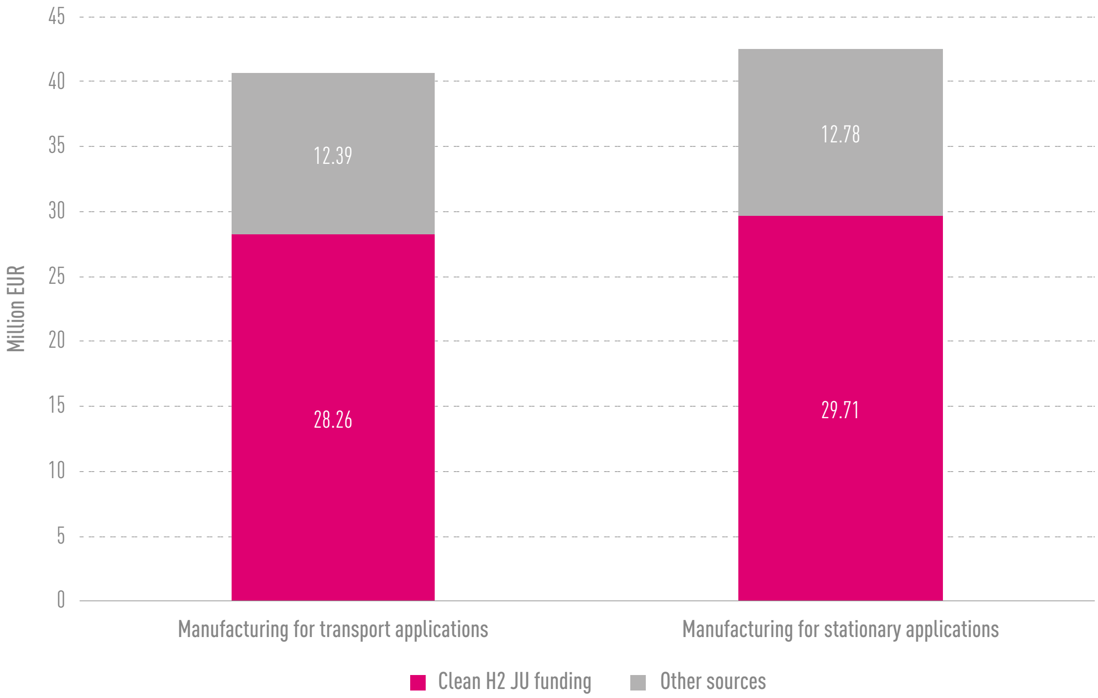
OBJECTIVES: The objective of pillar 7, as indicated in the SRIA, is to define and support the activities needed to strengthen the overall supply chain related to hydrogen technologies, recently identified by the European Commission as a strategic value chain for Europe. The overall goal of projects in this research area is to make possible efficient manufacturing of large volumes of PEM and solid oxide FC technologies, with improvements with respect to current production costs, FC performance and environmental impact.

Pillar 7 contains the following research areas:

1. **Manufacturing for stationary applications**
2. **Manufacturing for transport applications**
3. CRMs.

OPERATIONAL BUDGET: Between 2010 and 2020, the FCH and FCH 2 JUs supported 18 projects (Figure 29) relevant to this pillar with a total contribution of EUR 83 million and a contribution from partners of EUR 25 million. The historic distribution of total budgets for this pillar is shown in Figure 28 and indicates that 49 % of JU funding went to support seven projects on manufacturing for transport applications and 51 % was dedicated to 11 projects on manufacturing for stationary applications.

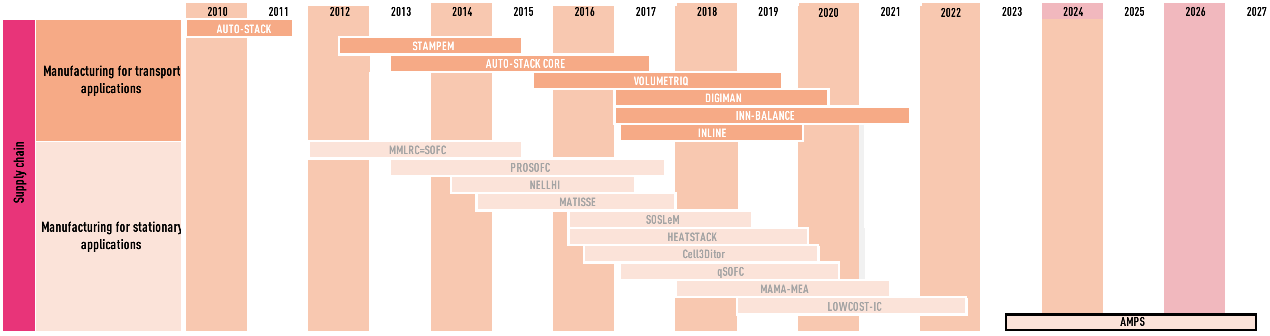
Figure 50: Funding for pillar 8 projects from 2008 to date



Source: Clean Hydrogen JU.

PROJECTS IN BRIEF: The Clean Hydrogen JU programme portfolio of pillar 7-related projects is shown in Figure 28. Although only one project shown under pillar 7 addresses supply chain issues, more than 20 other projects found under pillars 1 and 2, including some completed projects, also cover this topic.

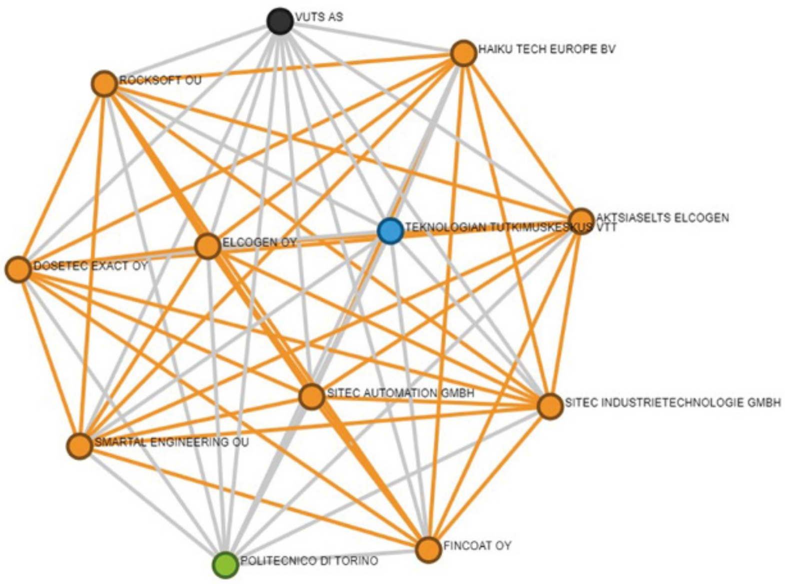
Figure 51: Project timelines for pillar 7 – supply chain



Source: Clean Hydrogen JU.

The TIM plots showing the main organisations and EU Member States contributing to pillar 7 are shown in Figure 52 and Figure 53. As there is only one project the plots only show the different participants and their countries.

Figure 52: TIM plot showing project participants under pillar 7

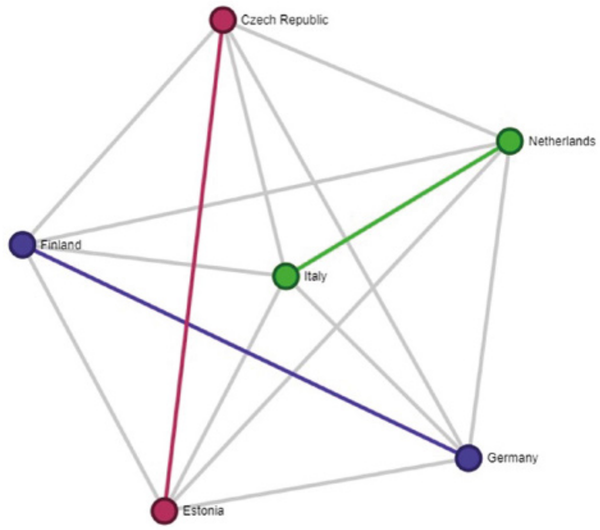


Top Participants

Participant	Number of Projects
Multiple participants	1

Source: TIM, JRC, 2024.

Figure 53: TIM plots showing EU Member States participation in pillar 7 projects



Member State	Number of Projects
Multiple States	1

Source: TIM, JRC, 2024.

Manufacturing for stationary applications

AMPS aims to develop and demonstrate cost-effective mass-manufacturing and quality-control methods, along with the associated software and equipment, on actual production lines. These methods, software and equipment can be sold directly by the participating companies as products, product lines and know-how.

PROJECT FACTSHEETS PILLAR 7

Manufacturing for stationary applications

AMPS

AMPS

AUTOMATED MASS PRODUCTION OF SOC STACKS

Project ID	101111882
PRR 2024	Pillar 7 – Supply chain
Call topic	HORIZON-JTI-CLEANH2-2022-04-01: Design and industrial deployment of innovative manufacturing processes for fuel cells and fuel cell components
Project total costs	EUR 8 711 520.00
Clean H_2 JU max. contribution	EUR 6 606 098.26
Project period	1.6.2023–31.5.2027
Coordinator	Teknologian tutkimuskeskus VTT Oy, Finland
Beneficiaries	Aktsiaselts Elcogen, Dosetec Exact Oy, Elcogen Oy, Fincoat Oy, Haiku Tech Europe BV, Politecnico di Torino, Rocksoft OÜ, SITEC Automation GmbH, SITEC Industrietechnologie GmbH, Smartal Engineering OÜ, VÚTS AS

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

PROJECT AND GENERAL OBJECTIVES

The objectives of AMPS are:

- automated high-speed cell production with integrated quality control;
- automated high-speed interconnect plate production and coating, with integrated quality control;
- automated high-speed stack assembly with integrated quality control;
- complete component tracking and optimised mass manufacturing by using virtual twins;
- assessment and demonstration of target stack manufacturing cost of < EUR 800/kWe at a production volume of 100 MW/year;
- establishment of a European supply chain of solid-oxide-cell-manufacturing equipment;
- automation of cell manufacturing process: > 80 %;
- automated visual inspection of cells: 5 s/cell;
- automation of interconnect-manufacturing process: > 90 %;
- stack assembly time (> 3 kWe, solid oxide fuel cell, 9 kWe, solid oxide electrolyser cell): < 1 hour;
- detection of critical defects (missing or misaligned components) in stack assembly: > 99.8 %;
- accuracy of component marking, reading, and tracking of selected parts: > 99 %;
- number of new products related to manufacturing solid oxide fuel cells / solid oxide electrolysis / components and quality control developed and commercialisation started: > 4.

NON-QUANTITATIVE OBJECTIVES

Circularity assessments and life-cycle assessments of the developed technologies, processes and methods are an integral part of the project.

PROGRESS AND MAIN ACHIEVEMENTS

The plan for a method to recycle cell production waste has been defined. In addition, specification and requirements for the interconnect laser welding process have been defined.

FUTURE STEPS AND PLANS

The next steps are the validation of automated raw material handling in cell production and the definition of methods for automated handling of stack components.

Clean Hydrogen Partnership
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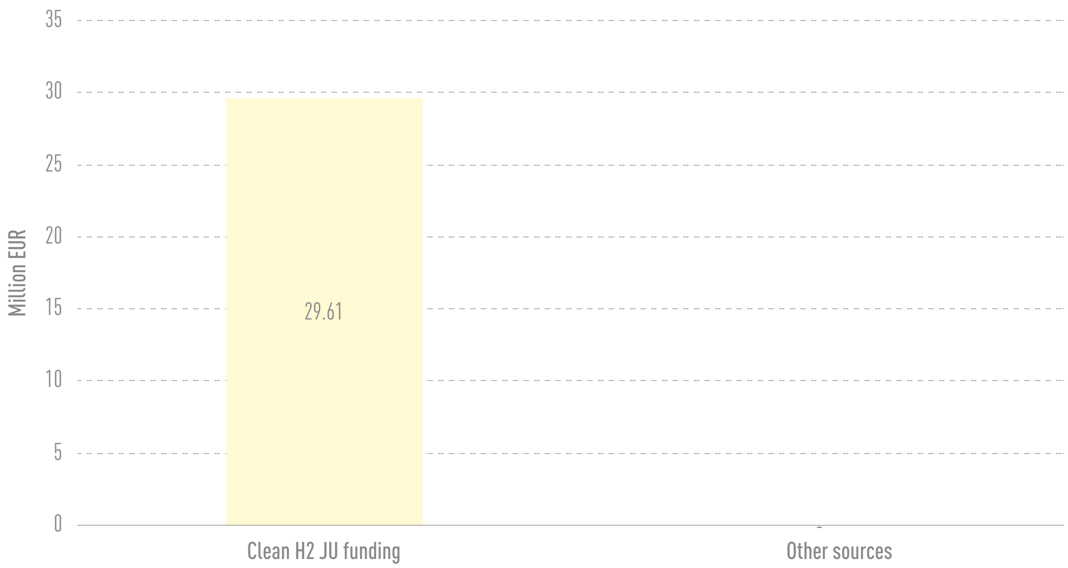
VIII. PILLAR 8 – STRATEGIC RESEARCH CHALLENGES

OBJECTIVES: Early-stage research actions must be supported by offering testing facilities to SMEs, enabling them to test their innovative technologies and advance them to a higher TRL for potential product development.

OPERATIONAL BUDGET: The allocated budget for pillar 8 can be seen in Figure 28. Around EUR 30 million of Clean Hydrogen JU funding is currently allocated to this pillar.

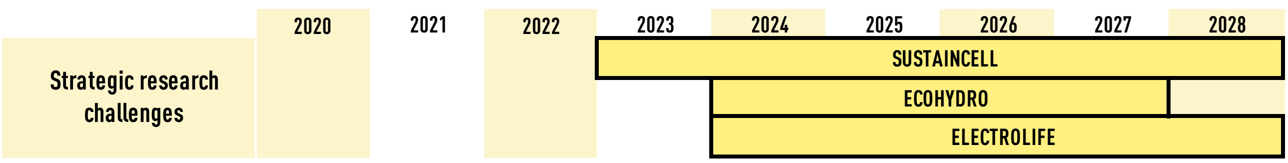
Figure 54: Funding for pillar 8 projects



Source: Clean Hydrogen JU.

PROJECTS IN BRIEF: The Clean Hydrogen JU programme portfolio of pillar 8-related projects is shown in Figure 28.

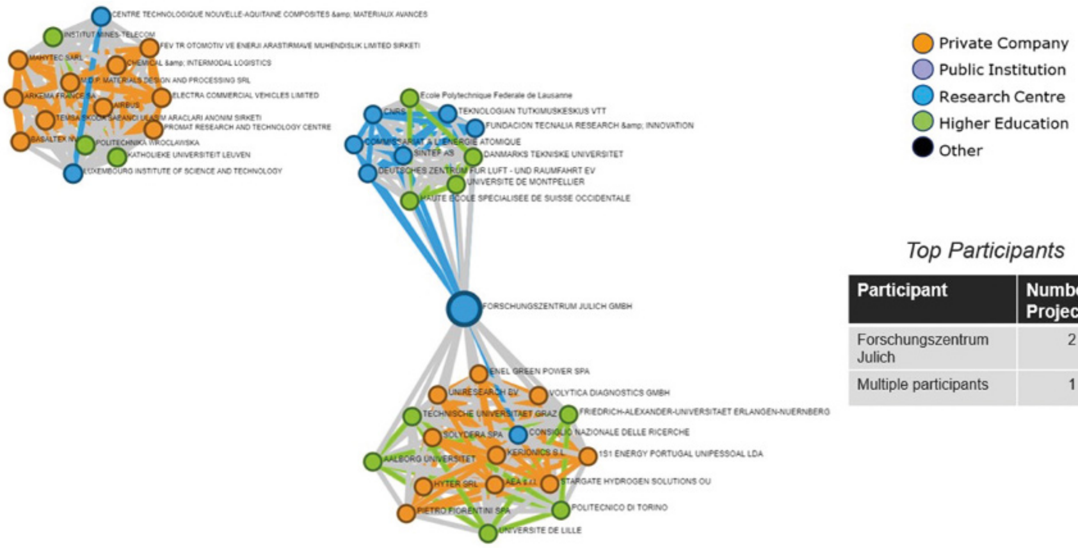
Figure 55: Project timelines for pillar 8 – strategic research challenges



Source: Clean Hydrogen JU.

The TIM plots showing the main organisations and EU Member States contributing to pillar 8 are shown in Figure 56 and Figure 57.

Figure 56: TIM plot showing project participants under pillar 8

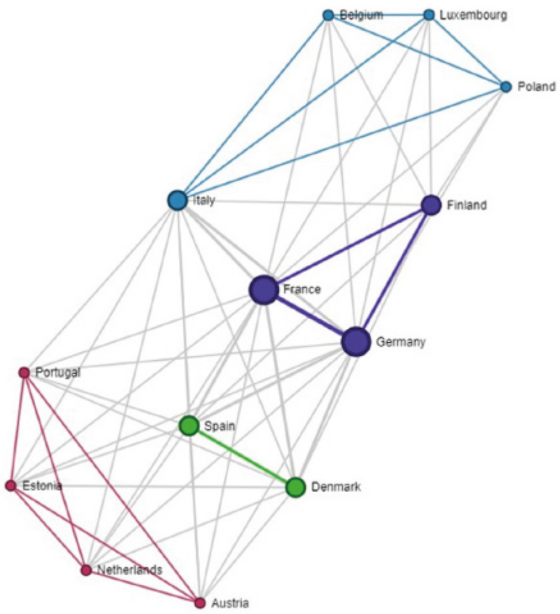


Top Participants

Participant	Number of Projects
Forschungszentrum Julich	2
Multiple participants	1

Source: TIM, JRC, 2024.

Figure 57: TIM plots showing EU Member States participation in pillar 8 projects



Member State	Number of Projects
France	3
Italy	2
Denmark	2
Spain	2
Germany	2

Source: TIM, JRC, 2024.

SUSTAINCELL aims to support European industry in developing the next generation of electrolyser and FC technologies (both LT and HT) by establishing a sustainable European supply chain of materials, components and cells. The project seeks to reduce reliance on CRMs, environmental impact and costs, and enhance performance and durability compared to existing technologies.

ECOHYDRO is the successor of THOR and aims to develop a novel, energy-efficient filament-winding process for hydrogen storage tanks using recyclable materials[125]. The project will improve thermoplastic acrylic resin for in-situ polymerisation, previously used in wind energy and marine applications, and for high-speed filament

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winding by optimising UV polymerisation of the resin and developing new filament-winding tools and equipment. The technology will be validated at four industrial demonstrators (TRL 4) for storage of either compressed gas or cryogenic liquid hydrogen at aboveground stations and in tube trailers, trucks, buses and aviation[126]. Additionally, recycling technology will be created to recover 100 % of carbon fibres and resin from hydrogen tanks at the end of their life. The recovered materials will be used for the rewinding process in the manufacturing of new tanks. This recycling and rewinding technology will significantly reduce the cost and carbon footprint of hydrogen storage tanks.

ELECTROLIFE intends to increase the efficiency of electrolysers by reducing the use of critical materials and extending the lifespan of the systems. This objective will be achieved through test campaigns to identify multiple degradation mechanisms on various scales, multiphysics simulations with superimposed degradation mechanisms, prototyping of cells and stack components and the construction of dedicated test benches. ELECTROLIFE is expected to reduce the average cost of ownership of electrolysers by 40 % for AEL and PEMEL and by 70 % for AEMEL and SOEL.

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PROJECT FACTSHEETS PILLAR 8

SUSTAINCELL

DURABLE AND SUSTAINABLE COMPONENT SUPPLY CHAIN FOR HIGH PERFORMANCE FUEL CELLS AND ELECTROLYSERS

Project ID	101101479
PRR 2024	Pillar 8 – Strategic research challenge
Call topic	HORIZON-JTI-CLEANH2-2022-07-01: Addressing the sustainability and criticality of electrolyser and fuel cell materials
Project total cost	EUR 9 993 652.00
Clean H_2 JU max. contribution	EUR 9 993 652.00
Project period	1.1.2023–31.12.2028
Coordinator	SINTEF AS, Norway
Beneficiaries	Centre national de la recherche scientifique, Commissariat à l'énergie atomique et aux énergies alternatives, Danmarks Tekniske Universitet, Deutsches Zentrum für Luft- und Raumfahrt EV, École polytechnique fédérale de Lausanne, Forschungszentrum Jülich GmbH, Fundacion Tecnalia Research and Innovation, Haute école spécialisée de Suisse occidentale, Teknologian tutkimuskeskus VTT Oy, Université de Montpellier

https://sustaincell.eu/

PROJECT AND GENERAL OBJECTIVES

The Sustaincell project aims to support European industry in developing next-generation electrolyser and fuel cell technologies by developing a sustainable European supply chain of materials, components and cells. This will be based on scientific breakthrough innovations, ecodesign guidelines and environmentally friendly manufacturing routes. The project will focus on developing new critical-raw-material (CRM)-lean and/or CRM-free materials and architectures, aiming to maximise functionalities and durability while decreasing CRM content per unit cell. The new flexible and scalable processing routes will exhibit higher productivity, reduced utilities consumption and reduced greenhouse gas emissions. The project will also develop enhanced recovery and treatment processes for optimising recovery and reuse of platinum group metals / CRMs and ionomers extracted from end-of-life stacks and production processes.

The project is led by SINTEF and will involve world-leading experts in the value chain of alkaline, proton-exchange membrane, anion-exchange membrane, solid oxide ion conducting and proton ceramic conducting electrolysers and fuel cells. The open innovation research will be actively communicated to European academia and industry to exploit the results of Sustaincell for the benefit of society.

NON-QUANTITATIVE OBJECTIVES

- Harvesting and expanding European knowledge and know-how on CRM identification, substitution, recovery and recycling strategies and value chains.
- Ensuring the replacement and/or reduction of CRMs per unit cell using eco-friendly processing methods.
- Increasing the yield of ionomers and CRMs recovered from used cells and membrane electrode assemblies, and from scrap and waste, by recycling.
- Contributing to the development of harmonised EU protocols.
- Validating new solutions in terms of gain in performance and durability at the single-cell level.
- Demonstrating the sustainability of at least three innovative solutions for each technology.
- Maximising the impact, uptake and acceptance of Sustaincell results by developing strategies for dissemination to, communication with and exploitation by academia, industries, policymakers, non-governmental organisations and the public.
- Establishing a suitable toolbox for efficient risk management and knowledge sharing between partners.

PROGRESS AND MAIN ACHIEVEMENTS

- Autumn school was co-organised by Sustaincell with four other EU projects (eCOCO2, Winner, Protostack, Single).
- School provided tutorial lectures on design, fabrication, characterisation, testing, and modelling of materials, components, cells, and stacks.
- Two milestones have been partially achieved, with performance targets achieved for several materials, durability needing validation.

FUTURE STEPS AND PLANS

- Prepare a workshop on life-cycle assessment in 2024;
- Continue the development and validation of CRM-free/lean electrocatalysts/ionomers/electrodes for both low- and high-temperature technologies;
- Carry out the round robin test;
- Increase interaction with external stakeholders and dissemination activities.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
SRIA (2021–2027)	CAPEX	€/kW	@ 100 MW: AEL 400, AEMEL 300, PEMEL 500, SOEL 520 @ 500 kWe, PEMFC 900	
	Min. CRMs/PGMs (other than Pt) recycled from scraps and wastes	%	50	
	Ionomers recycled from scrap and waste	wt%	80	
	Pt recycled from scrap and waste	wt%	99	
	Current density at the cell level for AEL, AEMEL, PEMEL, SOEL	A/cm² @ *x* V	2030: AEL 1 @ 1.8, AEMEL 1.5 @ 2, PEMEL 3 @ 1.8, SOEL 1.5 @ 1.2	
	CRMs as catalysts in AEL, AEMEL, PEMEL, PEMFC	mg/W	AEL 0.0, AEMEL 0.0, PEMEL 0.25, PEMFC (transport) < 0.25 mg/kW, PEMFC (stationary) 0.01 mg/Wel non-recoverable CRMs	
Project's own objectives	PEMFC electrical efficiency, non-recoverable CRM loading, degradation rate	%	~ 56 % (% lower heating value H_2), 0.01 mg/Wel, 0.2 %/1 000 h	

PDF ISBN 978-92-9246-431-8 doi:10.2843/715166 EG-05-24-218-EN-N

Clean Hydrogen Partnership

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ECOHYDRO

ECONOMIC MANUFACTURING PROCESS OF RECYCLABLE COMPOSITE MATERIALS FOR DURABLE HYDROGEN STORAGE

Project ID	101138008
PRR 2024	Pillar 8 – Strategic research challenge
Call topic	HORIZON-JTI-CLEANH2-2023-07-01: Advanced materials for hydrogen storage tanks
Project total cost	EUR 9 617 290.00
Clean H_2 JU max. contribution	EUR 9 617 290.00
Project period	1.1.2024–31.12.2027
Coordinator	Institut Mines-Télécom, France
Beneficiaries	Airbus, Arkema France SA, Basaltex NV, Centre Technologique Nouvelle-Aquitaine Composites & Matériaux Avancés, Chemical & Intermodal Logistics, Electra Commercial Vehicles Limited, FEV TR Otomotiv ve Enerji Araştirma ve Mühendislik Limited Sirketi, Katholieke Universiteit Leuven, Luxembourg Institute of Science and Technology, M.D.P. Materials Design & Processing SRL, MAHYTEC SARL, Politechnika Wrocławska, Promat Research and Technology Centre, Temsa Škoda Sabancı Ulaşım Araçları Anonim Şirketi

https://ecohydro-project.eu/

PROJECT AND GENERAL OBJECTIVES

Ecohydro's global objective is to ensure an economic process for manufacturing recyclable composite materials for durable hydrogen tanks through the usage of high-strength carbon fibre, low-viscosity thermoplastic liquid resin and instant *in situ* photopolymerisation for composite pressure vessels.

Ecohydro has six ambitious general objectives:

- identify and develop multifunctional sustainable materials enabling a circular design and reducing the whole-life cost of hydrogen storage solutions;
- develop standardised inspection and repair methods that improve safety aspects of hydrogen storage and increase the lifetime of hydrogen storage solutions;
- develop smart solutions that allow for cross-application uses of hydrogen storage to reduce the total number of storage tanks produced;
- demonstrate increased storage size and reduced capital cost for aboveground storage of hydrogen;
- demonstrate increased tube trailer payload, reduced capital cost and increased operating pressure for road transport of hydrogen;
- demonstrate increased gravimetric capacity, conformability, reduced capital costs and increased tank gravimetric efficiency for onboard storage of H_2 in heavy-duty truck and aviation applications.

PROJECT TARGETS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Trailer payload	kg	1 500	
	Operating pressure	bar	700	
	Trailer capital cost	€/kg	350	
	Gravimetric capacity	%	7	
	Cost	€/kg	600	
	Tank gravimetric efficiency	wt%	35	
	Storage size	t	20	
	Storage tank capital cost	€/kg H_2	300	

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