



Clean Hydrogen
Partnership



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PROGRAMME REVIEW REPORT 2022



https://www.clean-hydrogen.europa.eu/index_en
e-mail: info@clean-hydrogen.europa.eu
tel: +32 2 221 81 48; +32 2 221 84 10

Communication & Press:
e-mail: communications@clean-hydrogen.europa.eu
tel: +32 2 221 81 28

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PROGRAMME REVIEW

REPORT 2022

EUROPEAN PARTNERSHIP



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LIST OF ACRONYMS

AEL	Alkaline Electrolysis/Electrolyser
AEMEL	Anion Exchange Membrane Electrolysis/Electrolyser
AFIR	Regulation on Deployment of Alternative Fuel Infrastructure
APR	Aqueous Phase Reforming
APU	Auxiliary Power Unit
ASR	Area Specific Resistance
AST	Accelerated Stress Tests
AWP	Annual Working Plan
BEV	Battery Electric Vehicle
BoP	Balance of Plant
BoL	Begin of Life
BT	Benzyltoluene
CEN	The European Committee for Standardization
CENELEC	The European Committee for Electrotechnical Standardization
CCM	Catalyst Coated Membrane
CHP	Combined heat and power
CMSM	Carbon Molecular Sieve Membranes
CMR	Catalytic Membrane Reactor
CRM	Critical Raw Materials
CSP	Concentrating Solar Power
DBT	Dibenzyltoluene
EHP	Electrochemical Hydrogen Purification
EHSP	European Hydrogen Safety Panel
EIS	Electrochemical Impedance Spectroscopy
ETS	EU Emission Trade System
EU	European Union
FC/FCS	Fuel Cell/Fuel Cell System
FCB	Fuel Cell Bus
FCT	Fuel Cell Truck
FCEV	Fuel Cell Electric Vehicle
FCHO	Fuel Cells and Hydrogen Observatory
FCH JU	Fuel Cells and Hydrogen Joint Undertaking in the 7 th R&I Framework programme, from 2008 to 2013.
FCH 2 JU	The second Fuel Cells and Hydrogen Joint Undertaking from 2014 to 2020, under the H2020 R&I Framework programme (now replaced by the Clean Hydrogen Joint Undertaking).
FP7	EU's 7th framework programme
GHG	Greenhouse Gases
H2020	Horizon 2020
HE	Horizon Europe
HHV	Higher Heating Value
HDV	Heavy-duty Vehicle

HRS	Hydrogen Refuelling Station
HT	High Temperature
HMT	Hydro-Metallurgical Technology
HTT	Hydrothermal Treatment
HTP	Hydrogen Territories Platform
ICT	Information Communication Technology
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IPCEI	Important Projects of Common European Interest
IPHE	International Partnership for Hydrogen and Fuel Cells in the Economy
IRENA	International Renewable Energy Agency
ISO	International Organisation for Standardization
JRC	Joint Research Centre of the EC
JU	Joint Undertaking
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LCSA	Life Cycle Sustainability Assessment
LH₂	Liquid Hydrogen
LHV	Lower Heating Value
LOHC	Liquid Organic Hydrogen Carrier
LT	Low Temperature
m-CHP	micro-CHP
MAIP	FCH JU's Multi-Annual Implementation Plan (2008-2013)
MAWP	FCH 2 JU's Multi-Annual Work Plan (2014-2020)
MDPC	Monitoring, Diagnostic, Prognostic and Control Tool
MEA	Membrane Electrode Assembly
MHV	Materials handling vehicles
MOF	Metal Organic Framework
MRL	Manufacturing Readiness Level
NG	Natural gas
OEM	Original equipment manufacturer
OSR	Oxidative Steam Reformer
PCC	Proton Conducting Ceramic Electrochemical Cells
PCCEL	Proton Conducting Ceramic Electrolysis/Electrolyser
PCD	Porous Current Distributors
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
PRD	Programme Review Days
PSA	Pressure Swing Adsorption
PTL	Porous Transfer Layer
PV	Photovoltaic
R&I	Research and Innovation
R&D	Research and Development
RCS	Regulations, Codes and Standards
RES	Renewable Energy Sources
rSOC	Reversible Solid Oxide Cell
SBA	Single Basic Act
SET	Strategic Energy Technology
SME	Small and medium-sized enterprise
SoA	State-of-the-art
SOEC	Solid Oxide Electrolyser Cell
SOEL	Solid Oxide Electrolysis/Electrolyser
SOFC	Solid Oxide Fuel Cell
SRIA	Strategic Research and Innovation Agenda of the Clean Hydrogen JU
TIM	Tools for Innovation Monitoring
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
TSA	Temperature Swing Absorption
VPS	Vacuum Plasma Spray Systems

EXECUTIVE SUMMARY

The EU has supported research and innovation on hydrogen for many years. The Clean Hydrogen Joint Undertaking (Clean Hydrogen JU) is the continuation of the successful Fuel Cell and Hydrogen JUs (FCH JU and FCH 2 JU), under the EU's 7th Framework Programme (FP7) and Horizon 2020 (H2020) respectively, with a goal to ensure the development of a full hydrogen supply chain to serve the European economy. The research and innovation activities of the Clean Hydrogen JU are related primarily to the production of clean hydrogen, distribution, storage and end use applications of low carbon hydrogen in hard to abate sectors.

The purpose of the periodic Programme Review is to ensure that the Clean Hydrogen JU Programme is aligned with the strategy and objectives set out in its founding Regulation, as further elaborated in its Strategic Research and Innovation Agenda (SRIA) for 2021-2027. The Joint Research Centre of the EC (JRC) was entrusted with Programme Review as part of its activities under the multiannual Framework Contract signed with the JU since 2017, based on the data collection of relevant information from projects that was carried out by the Programme Office using multiple sources (mainly TRUST Platform and EU-SURVEY). Starting from 2022, the scope of the Programme Review has broadened compared to previous years. At the core of the Programme Review remains still the Annual Programme Technical Assessment performed by JRC, together with the annual event, the EU Research Days (previously Programme Review Days) and the publication of the Clean Hydrogen JU project fiches.

The Annual Programme Technical Assessment covers 98 projects active between January 2021 - March 2022. In line with the new programme structure of the Clean Hydrogen JU, the reviewed projects have been assigned to seven "Review Pillars": Hydrogen Production, Hydrogen Storage and Distribution, Hydrogen End Uses – Transport, Hydrogen End Uses – Clean Heat and Power, Cross-Cutting Issues, Hydrogen Valleys and Hydrogen Supply Chains. Each Pillar consists of a set of Research Areas which group projects covering similar, related topics. The programme assessment is performed for each Research Area.

Under Hydrogen Production (Pillar 1), 22 projects contribute towards achieving the techno-economic objective of making clean hydrogen production competitive and enabling the scale-up of these technologies. In low-temperature (LT) electrolysis, significant progress has been made in Alkaline Electrolysis (AEL) and Proton Exchange Membrane Electrolysis (PEMEL) towards reliability of green hydrogen production solutions for hard to abate industrial processes, reduction of the response time and finally upscale to a multi-MW level. Also, three projects are progressing in the low Technology Readiness Level (TRL) Anion Exchange Membrane Electrolysis (AEMEL) technology. In high temperature (HT) electrolysis, emphasis has been given mainly in the Solid Oxide Electrolysis (SOEL) technology funding both high and low and high TRL projects, with one project working also on the Proton Conducting Ceramic Electrolysis (PCCEL) technology. Finally, other routes of renewable hydrogen production are also being explored by two projects.

Hydrogen Storage and Distribution (Pillar 2) are critical to build the necessary logistics infrastructure to store and transport hydrogen. There are various options to transport and store hydrogen investigated by 11 reviewed projects in total, with many technologies that need to be investigated and supported: Aboveground and underground storage, injection in the gas grid, liquid H₂ carriers, compression, purification and metering solutions and HRS.

Hydrogen uses in Transport (Pillar 3) has been substantially supported by the predecessor of the Clean Hydrogen JU, validating and demonstrating a lot of Fuel Cell (FC) applications (materials handling vehicles, passenger cars and buses) which are now ready for market deployment. Pillar 3 with 28 projects encompasses both research projects and demonstration initiatives to fulfil these objectives and is divided into seven research areas: building blocks, aviation, heavy duty vehicles, waterborne applications, rail applications, buses/coaches and cars.

Under Pillar 4, European supply chain actors are supported to develop a portfolio of Hydrogen End Uses for Clean Heat and Power solutions, for all end users' needs and across all system sizes. Most support was provided to solutions running on 100% hydrogen, although there is still support to solutions running on a hydrogen mixture in

the gas grid up to 20% during the transition phase. The research areas include micro Combined Heat and Power (m-CHP) applications, commercial and industrial size systems, off-grid or back-up gensets and other research areas in both Proton Exchange Membrane Fuel Cells (PEMFC) and Solid Oxide Fuel Cell (SOFC) technologies and 13 projects are reviewed accordingly.

Pillar 5, with 15 reviewed projects, covers the Cross-Cutting topics structured around three research areas with the following overarching objectives: one is relevant to Sustainability, Life Cycle Sustainability Assessment (LCSA), recycling and eco-design, another one to education and public awareness (a complete range of tools to train and educate all stakeholders are produced) and the last one is on safety, Pre-Normative Research (PNR) and Regulations, Codes and Standards (RCS).

Hydrogen Valleys (Pillar 6) constitute a concept which started in 2017 with the Regions Initiative of the JU, towards integration of hydrogen technologies within defined geographical areas. They are now one of the main priorities of the JU for scaling-up hydrogen deployments and creating interconnected hydrogen ecosystems across Europe. Clean Hydrogen JU is funding three such projects so far, centred around the production of hydrogen from renewable sources.

Also, the objective of Pillar 7 is to define and support the activities needed to strengthen the overall Supply Chain related to hydrogen technologies and to support the massive hydrogen production scale-up for the coming years. Currently three projects address a wide array of supply chain topics, from processing of raw materials to manufacturing of specialised materials, manufacturing of high quality and low-cost components at a large scale, further recycling and waste management.

In addition to the projects, a number of studies performed this year show the strong come back of the FC market fundamental figures after the pandemic and the constant increase of the hydrogen market. In this context, the Clean Hydrogen JU published two interesting reports in September. The first one, on the impact of deployment of electric vehicle infrastructure, shows that the most cost-effective solution is to combine Battery Electric Vehicles (BEVs) and Fuel Cell Electric Vehicles (FCEVs) infrastructures. The second one, published under the Hydrogen Valleys Platform, confirms that Hydrogen Valleys already play an integral and increasing part in addressing the paradigm for producing, importing, transporting and using clean hydrogen effectively.

The Hydrogen Valleys Platform also conducted a survey, exploring the barriers for Hydrogen Valleys, which can be considered to apply largely for the whole hydrogen sector. At a global scale, permitting and finding experienced staff constitute the biggest barriers. In the EU, the major barriers are the missing or strict regulations and the tax levies on electricity from Renewable Energy Sources (RES), together with financial aspects, like the funding and the project's business case. The public financial support and customer commitments to de-risk the financial model are also very important, which shows the important role for the JU and other public funding instruments.

01. INTRODUCTION

The EU has supported research and innovation on hydrogen for many years, starting through traditional collaborative projects, and subsequently mainly with the FCH JU. These efforts have enabled several technologies to come close to maturity¹, alongside the development of high-profile projects in promising applications², and to achieve EU global leadership for future technologies, notably on electrolyzers, hydrogen refuelling stations and megawatt-scale fuel cells. EU funded projects also allowed improvement in the understanding of the applicable regulation for boosting the production and utilisation of hydrogen in the EU.

To ensure a full hydrogen supply chain to serve the European economy, further research and innovation efforts are still required. In the current period, EU has planned a number of actions towards this direction, including the support through Horizon Europe (HE)³ – EU's key funding programme for research and innovation - and the EU Emission Trade System (ETS) Innovation Fund, the integration of hydrogen in the Strategic Energy Technology (SET) Plan⁴ activities, co-leading the Clean Hydrogen Mission⁵ launched under Mission Innovation, but also via targeted support through dedicated instruments (e.g. InnovFin Energy Demonstration Projects, InvestEU).

The most important of these actions was the establishment of the Clean Hydrogen JU⁶ to continue to support Research and Innovation (R&I) activities in the Union in clean hydrogen solutions and technologies, under Horizon Europe, and in synergy with other EU initiatives and programmes. The Clean Hydrogen JU is the continuation of the successful Fuel Cell and Hydrogen JUs (FCH JU and FCH 2 JU), under FP7 and H2020 programmes respectively.

These activities are guided to a large extent by EU's Hydrogen Strategy⁷ and the policy developments in this context, contributing to its implementation.

The multi-annual programme of the Clean Hydrogen JU is described in its Strategic Research and Innovation Agenda⁸. Compared to the past FCH JU Programmes, the SRIA describes a much broader set of activities on all areas and applications where hydrogen is expected to play a role, across energy, transport, building and industrial end-uses. At the same time, with many more research Programmes including hydrogen technologies in their scope, 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 Union scientific capacity to accelerate the development and improvement of advanced clean hydrogen market ready applications.

To achieve these ambitious objectives, the EU decided to almost double the budget of the Clean Hydrogen JU in comparison to its predecessor, FCH 2 JU, by supporting it with EUR 1 billion⁹ for the period 2021-2027, complemented by at least an equivalent amount of private investment from the private members of the JU.

1. E.g. buses, passenger cars, vans, material-handling vehicles, and refuelling stations.

2. E.g. e-fuels for aviation, hydrogen in rail, and the maritime sector.

3. Regulation (EU) 2021/695 establishing Horizon Europe – the Framework Programme for Research and Innovation, OJ L 170, 12.5.2021, p. 1–68.

4. https://energy.ec.europa.eu/topics/research-and-technology/strategic-energy-technology-plan_en

5. <http://mission-innovation.net/missions/hydrogen/>

6. Council Regulation (EU) 2021/2085 of 19 November 2021 establishing the Joint Undertakings under Horizon Europe

7. COM(2020) 301 final, A Hydrogen Strategy for a climate neutral Europe.

8. SRIA, Clean Hydrogen JU website

9. Plus 200 million for Hydrogen Valleys, as mentioned in the European Commissions' Communication "RePower EU Plan", COM(2022) 230

02. PURPOSE AND SCOPE OF PROGRAMME REVIEW 2022

The purpose of the periodic Programme Review is to ensure that the Clean Hydrogen JU Programme is aligned with the strategy and objectives set out in the SBA, as further elaborated in its SRIA for 2021-2027. It is performed in a similar manner as for its predecessors, FCH JU and FCH 2 JU, and their respective founding Regulations and multi-annual work plans: Multi-Annual Implementation Plan (MAIP)¹⁰ for 2008-2013 under FP7 and Multi-Annual Work Plan (MAWP)¹¹ for 2014-2020 under H2020.

The Programme Review is an exercise dating back to 2011. Initially, between 2011 and 2016, it was carried out by external experts from research and industry, both European and non-European, as well as by members of the FCH 2 JU Scientific Committee.

In the case of FCH JU and FCH 2 JU, their objectives mainly concerned research objectives¹². Therefore, the Programme Review focused on assessing the progress against the multi-annual targets for FCH technologies in Europe in the form of specific and quantitative key performance indicators (KPIs) described in the multi-annual plans, covering parameters such as cost, durability and performance.

As follow-up to a recommendation¹³ by the Internal Audit Service of the Commission, as of 2017 Programme Review was performed following a different procedure to that applied in the previous years. Upon proposal by the Programme Office and following endorsement by the Governing Board, the JRC was then entrusted with the 2017 Programme Review as part of its activities under the multiannual Framework Contract signed between FCH 2 JU and JRC. The data collection of relevant information from projects was carried out by the Programme Office using multiple sources, including the TRUST (Technology Reporting Using Structured Templates)¹⁴ platform, project deliverables and a dedicated EU-Survey. After the signature of a Declaration of Confidentiality and Conflict of Interest, the assessment of the Programme was then performed by JRC, preparing a detailed report with observations on the major accomplishments of the projects, difficulties encountered and evaluating the performance of the Programme against the KPIs.

Starting with 2022, the scope of the Programme Review has further broadened compared to previous years. At the core of the Programme Review remains still the Annual Programme Technical Assessment performed by JRC¹⁵, together with the annual event, the EU Research Days - previously Programme Review Days) - and the publication of the Clean Hydrogen JU project fiches (previously called posters). Focusing on the JRC assessment, its scope is to review the annual progress of the Clean Hydrogen JU Programme towards its multi-annual research targets, as reflected by the SRIA technology KPIs, while also identifying gaps in the Programme and providing recommendations on how to better meet its multiannual programme objectives and targets.

The JRC recommendations are then complemented by the independent opinions of the wider scientific community, gathered during the EU Hydrogen Research Days (including Programme Review)¹⁶ as foreseen in Article 82 (d) of the

10. [MAIP, Clean Hydrogen JU website](#)

11. [MAWP, Clean Hydrogen JU website](#)

12. On top of the horizontal objectives of FP7 and H2020, common to all Programmes.

13. Final Audit Report on Performance management of the FCH 2 JU activities (Internal Audit Service Report: IAS.A2-2016-FCH 2 JU-003)

14. <https://trust.fch.europa.eu/ui/projects>

15. A summary of the JRC Programme Technical Assessment per Pillar can be found in the second part of this report, as introductory information for each Pillar.

16. https://www.clean-hydrogen.europa.eu/european-hydrogen-week-2022_en

Single Basic Act¹⁷ (SBA), as well as the input of the JU's Stakeholders Group, on the strategic and technological priorities to be addressed by the Clean Hydrogen JU. Additionally, the Programme Review reports on possible relevant studies commissioned by the JU, certain major reports published by international bodies and selected international developments, providing a more holistic picture on the wider developments in the hydrogen sector and how the Clean Hydrogen JU activities fit in this wider context. Moreover, it also summarises observed technological, economic and societal barriers to market entry, tasked to the JU by the SBA Article 74 (a). Considering all the above information, the Program Review closes by reporting on the progress towards the JU's strategic objectives through the relevant KPIs defined in its SRIA¹⁸.

The inclusion of all these topics in the Programme Review Report, allow it to go beyond the simple monitoring of the Programme, but become also an important input for the next Annual Work Programmes and the identification of research areas and topics for the forthcoming Calls.

17. Regulation (EU) 2021/2085 - adopted by the Council of the European Union on 19 November 2021 - concerning the establishment of Joint Undertakings under Horizon Europe.

18. Annex I of the SRIA

03. OVERVIEW OF JRC'S ANNUAL PROGRAMME TECHNICAL ASSESSMENT 2022

The Annual Programme Technical Assessment has included all projects up to the 2020 Calls for Proposals that were ongoing¹⁹ in the period January 2021 - March 2022. The current Annual Programme Technical Assessment therefore covers 98 projects, of which two began under FP7 and 96 under H2020. Out of the 98 considered projects, 25 projects have been running for a timespan of less than or equal to 13 months up to the cut-off date (March 2022). Compared to projects with a longer running life, it is more difficult to make a correct and fair assessment of the younger projects. This implies that the findings of the review are more representative for older projects.

In line with the new programme structure of the new Clean Hydrogen JU, explained in the SRIA, the reviewed projects have been assigned to seven "Review Pillars":

Pillar 1: Hydrogen Production

Pillar 2: Hydrogen Storage and Distribution

Pillar 3: Hydrogen End Uses - Transport

Pillar 4: Hydrogen End Uses – Clean Heat and Power

Pillar 5: Cross-Cutting Issues

Pillar 6: Hydrogen Valleys

Pillar 7: Hydrogen Supply Chains

In the past the projects were assigned to "review panels", based on the programme structure of FCH 2 JU MAWP. There were 6 panels: 2 for transport end-uses split based on the project TRL (panels 1 and 2), 2 for energy end-uses also split on the project TRL (panels 3 and 4), one covering production, distribution and storage (panel 5) and one for cross-cutting issues (panel 6). In relation to the new Review Pillars, projects in panels 1 and 2 have moved under Pillar 3 and when relevant under Pillar 7, most projects in panels 3 and 4 moved under Pillar 4, panel 6 has in essence been renumbered to Pillar 5, while the projects in panel 5 have been split mainly between Pillars 1, 2, 6 and 7.

Each Pillar is characterised by a wide range in scope, activities and applications of the included projects. Therefore, each Pillar consists of a set of Research Areas which group projects covering similar, related topics. The programme assessment is performed for each Research Area. This split is presented in Table 1 below.

19. "Ongoing" means between project start date and project end date.

Table 1: Pillars for the 2022 Programme Review.

PILLARS	RESEARCH AREAS	RESEARCH TOPICS
1) Hydrogen Production	1 - Low temperature electrolysis	Projects targeting AEL, PEMEL and AEMEL
	2 - High-temperature electrolysis (incl. co-electrolysis)	Projects targeting SOEL and PCCEL
	3 - Other hydrogen production methods	Projects covering reformer development for distributed hydrogen production and thermochemical hydrogen production are covered in this review
2) Hydrogen storage and distribution	4 - Aboveground storage	Projects addressing optimisation and deployment of large-scale solid state storage solution
	5 - Underground storage	Projects targeting the feasibility, risks and impact of H ₂ underground storage
	6 - H ₂ in the natural gas grid	Projects assessing the effect of H ₂ on transmission (High pressure) Natural Gas (NG) pipeline
	7 - Liquid H ₂ carriers	Projects focusing on the improvement of the roundtrip efficiency of conversion and system cost
	8 - Compression, purification and metering solutions	Projects demonstrating feasibility of direct separation of H ₂ from NG and material research on proton conducting ceramic electrochemical cells (PCC)
	9 - H ₂ refuelling stations	Projects addressing reliability and availability issues indicated by operation of existing Hydrogen Refuelling Stations (HRS)
	10- Hydrogen transportation (pipelines, road transport and shipping)	<i>currently not covered by any projects</i>
	11 - Hydrogen distribution (pipelines)	<i>currently not covered by any projects</i>
3) Hydrogen end uses - transport	12 - Building Blocks	Projects focusing on material, design and system optimisation for LT and HT PEMFC
	13 - Heavy Duty Vehicles	Projects addressing optimisation of BoP components and architectures design to meet Heavy-Duty Vehicles (HDV) needs
	14 - Waterborne Applications	Projects focusing on improving access to the market for hydrogen, its derivatives and FCs, initially on smaller vessels
	15 - 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

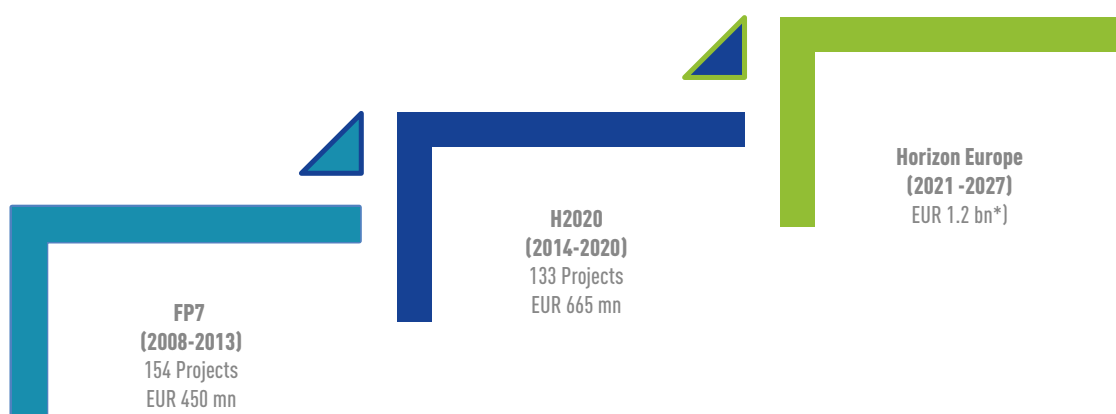
PILLARS	RESEARCH AREAS	RESEARCH TOPICS
	16 – Aviation Applications	Projects addressing optimisation of Balance of Plant (BoP) components and architectures design to meet aviation needs
	17 – Bus/Coaches	Projects with the objective of improve the deployment of hydrogen in this segment
	18 - Cars	Projects with the objective of improve the deployment of hydrogen in this segment
4) Hydrogen end uses – Energy	19 - m-CHP	Project exploring the deployment of PEMFC and SOFC for micro-Cogeneration
	20 - Commercial Size CHP	Demonstration projects for commercial size CHP using SOFC and HT PEMFC
	21 – Industrial Size CHP	Project exploiting PEMFC technology at industrial size
	22 – Off-grid/back up/genset	Demonstration projects exploring the application of Proton Exchange Membrane (PEM), Solid Oxide and Alkaline hydrogen technologies (FC and electrolyzers)
	23 – Next generation degradation and performance & Diagnostic	Exploration projects for utilization of biogas fed with a SOFC CHP system and use of Electrochemical Impedance Spectroscopy (EIS) technology for monitoring & diagnostic purposes
5) Cross-cutting topics	24 - Sustainability, Life Cycle Sustainability Assessment, recycling and eco-design	Projects addressing needs to define guideline for sustainability assessment
	25 - Education and Public Awareness	Projects aiming to increase the knowledge on hydrogen technology at educational level (schools /universities)
	26 - Safety, Pre-Normative Research and Regulations, Codes and Standards	Projects focusing on improving knowledge on hydrogen risk of utilization and definition of protocol for permitting
6) Hydrogen Valleys	27 – H ₂ Valley	Projects aiming to develop a hydrogen integrated system when favourable conditions at industrial or geographical point of view
7) Hydrogen Supply Chains	28 – Manufacturing for stationary applications	Projects addressing optimisation of materials and/or BoP components and architectures design to meet stationary application needs
	29 – Manufacturing for transport applications	Projects addressing optimisation of BoP components and architectures design to meet transport application needs

04. BUDGET ANALYSIS

The predecessors of the Clean Hydrogen JU, i.e., FCH JU (2008-2013) & FCH 2 JU (2014-2020), have supported and funded in total 287 projects, with a combined budget of more than EUR 1 billion, complemented by almost an equal funding from non-EU sources (e.g.: regional, national, or private²⁰).

In line with the ambition and the objectives set for the Clean Hydrogen JU, the EU almost doubled its budget in comparison to its predecessor, supporting it with over EUR 1 billion for the period 2021-2027. As a result, the overall programme funding, including private investment from the private members of the JU, will be reaching approximately EUR 2 billion. More, to accelerate hydrogen projects under the RePower EU Plan, the Commission will top-up an additional funding of EUR 200 million to the overall budget for the Clean Hydrogen JU goal, to double the number of Hydrogen Valleys.

Figure 1: Sequence of deployed budget (*including foreseen funding for hydrogen valleys from REPower EU Plan).



Source: Clean Hydrogen JU

The previously existing Joint Undertakings, FCH JU and FCH 2 JU, were both serving the goal of supporting and spurring hydrogen related research and demonstration projects, yet having different objectives, focusing on different research areas. In the following paragraphs a more detailed overview per Programme is provided, as also their budget spending allocation.

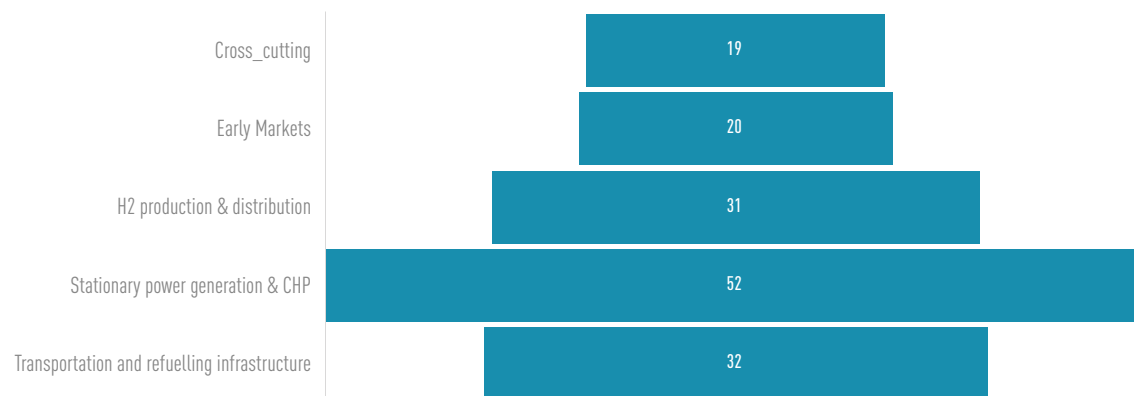
4.1. FRAMEWORK PROGRAMME 7 (FP7)

Under the framework of FP7 program (2008 – 2013) the EC contributed to the FCH JU activities a total of EUR 450 million. The aim of the FCH JU was to accelerate the development and deployment of fuel cells and hydrogen technologies by executing an integrated European programme of Research and Development (R&D) activities.

The representatives of the Industry and Research Groupings working in consultation with the Commission identified specific priority topics, emphasising the key importance of five pillars, i.e., “Transport & Refuelling Infrastructure”, “Hydrogen Production & Distribution”, “Stationary Power Generation & CHP”, “Early Markets” and “Cross-cutting Activities”. The number of the funded projects by pillar (application area) is displayed in Figure 2.

20. Private investment from the private members and stakeholders of the JU.

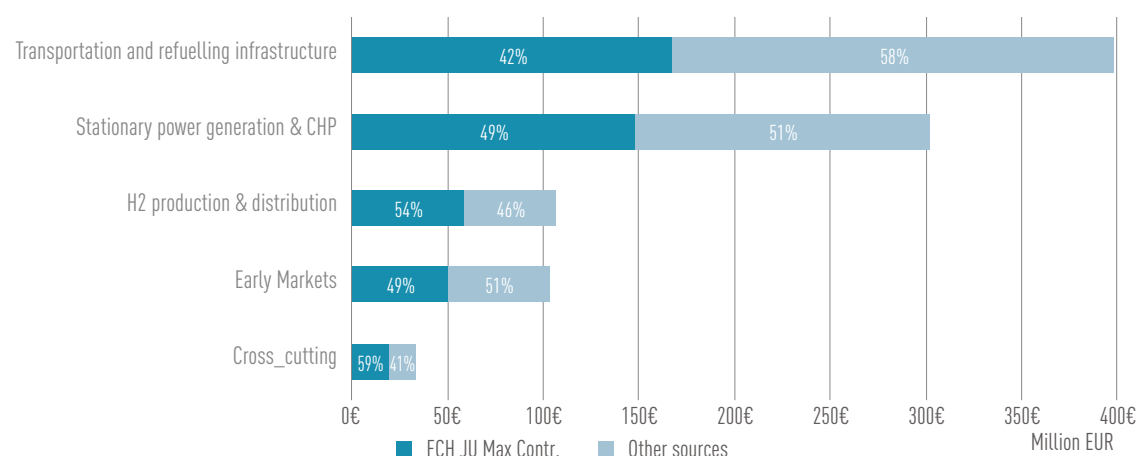
Figure 2: Number of projects per Pillar funded by FCH JU under FP7.



Source: Clean Hydrogen JU

The aforementioned FCH JU funds were complemented by additional private funds. In Figure 3 one can see the budget breakdown between FCH JU and private funds per pillar, invested for the duration of the FP7 program to achieve the acceleration of development and deployment of fuel cells and hydrogen technologies.

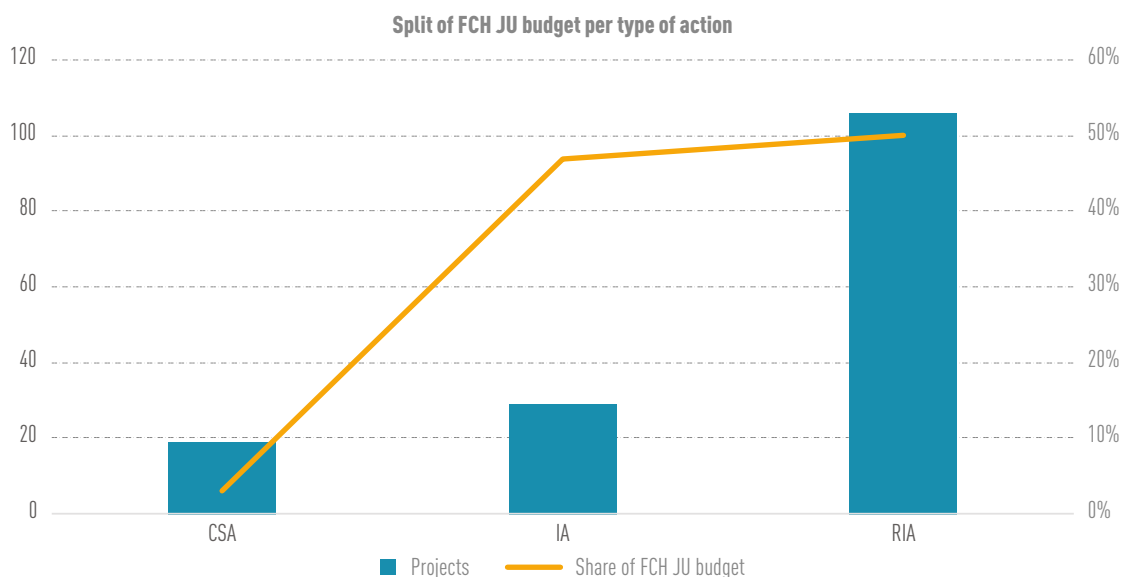
Figure 3: Percentage of funds contributed by FCH JU and other entities under FP7.



Source: Clean Hydrogen JU

FCH JU funded a combination of research and innovation actions (RIA) and innovation actions (IA), together with coordination and support actions (CSA), in order to reach its objectives. The split of the budget by such actions is presented in Figure 4.

Figure 4: Number of projects for research and demonstration (left axis) and the respective percentage of funds allocation during FP7 (right axis) under FP7.



Source: Clean Hydrogen JU

4.2. HORIZON 2020 (H2020)

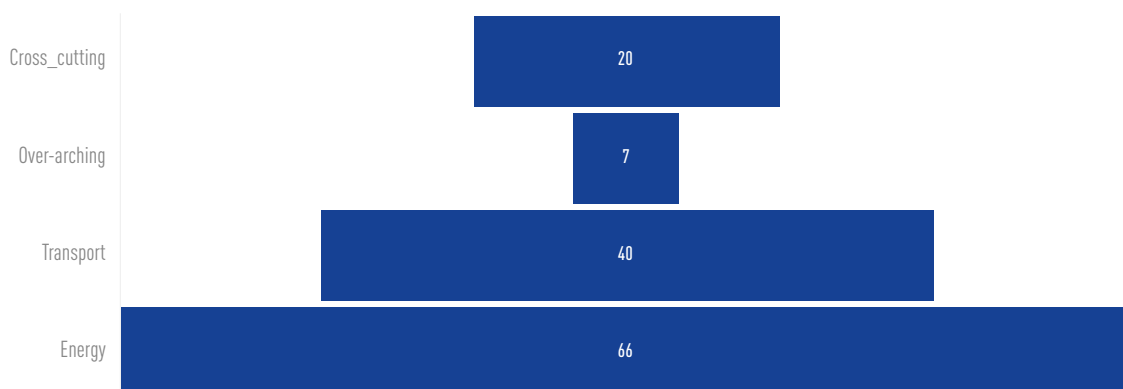
The Horizon 2020 programme (2014 – 2020) comprised industry-led applied research, development and demonstration activities, including prototyping, piloting and testing, for fuel cell and hydrogen technologies. The FCH 2 JU, as successor of FCH JU, provided a stable, long-term instrument supporting the necessary investments required to introduce FCH technologies into the marketplace.

The main strategic objectives of FCH 2 JU were to (i) boost the share of FCH technologies in a sustainable, low-carbon energy and transport system, (ii) ensure a world leading competitive European FCH industry and (iii) secure inclusive growth for Europe's FCH industry, increasing/safeguarding jobs.

The implementation of the FCH 2 JU Programme of research & innovation, and innovation actions for fuel cell and hydrogen technologies during H2020 is structured around four pillars, dedicated respectively to "Transport", "Energy Systems", "Overarching projects" integrating both Transport and Energy technologies, and "Cross-cutting" research activities. The priorities and budget distribution among the various pillars was agreed by the Governing Board, after consultation of the members of the FCH 2 JU.

The total contribution from the EC to the FCH 2 JU funded projects account for EUR **646** million allocated to a number of funded projects by pillar (application area) as displayed in Figure 5.

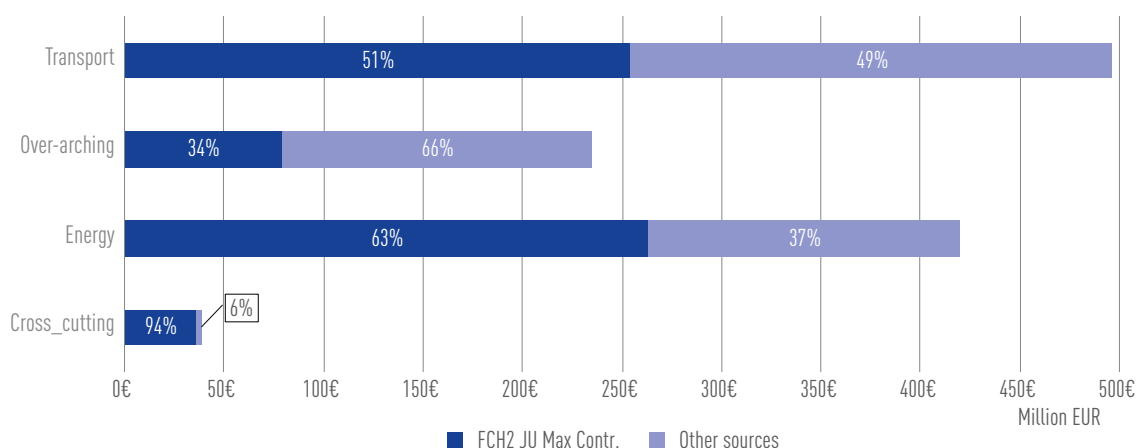
Figure 5: Number of projects per Pillar funded by FCH 2 JU under H2020.



Source: Clean Hydrogen JU

The proportion of the FCH 2 JU and private funds per pillar, as contributed for the duration of the H2020 program, in order to grow the share of FCH technologies securing inclusive growth for Europe's FCH industry, is presented in Figure 6.

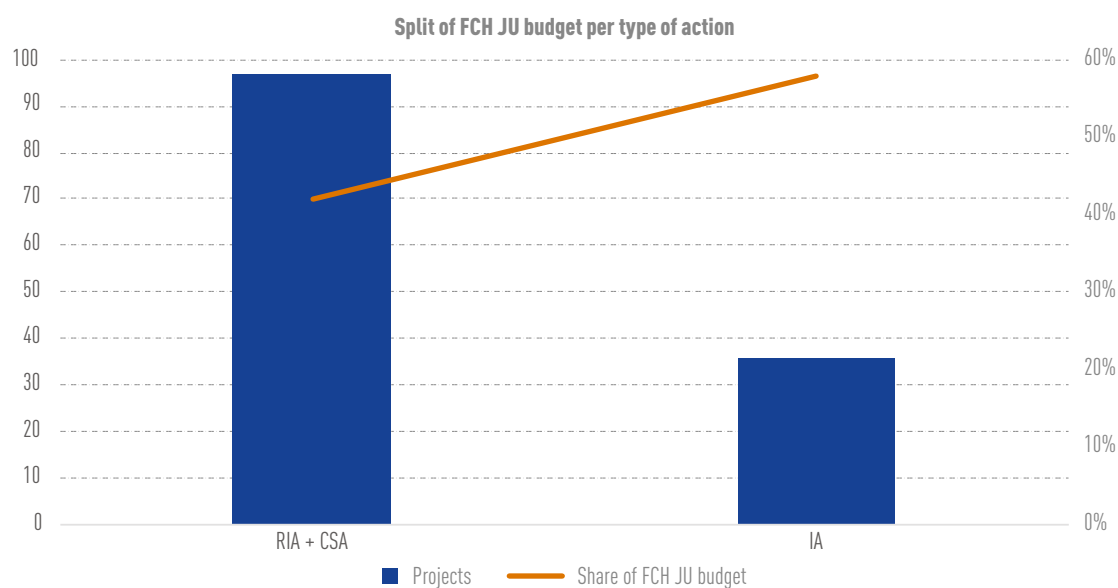
Figure 6: Percentage of funds contributed by FCH 2 JU and other entities under H2020.



Source: Clean Hydrogen JU

FCH JU funded a combination of research and innovation actions (RIA) and innovation actions (IA), together with coordination and support actions (CSA), in order to reach its objectives. The split of the budget by such actions is presented in Figure 7.

Figure 7: Number of projects for research and demonstration and the respective percentage of funds allocation during H2020²¹.



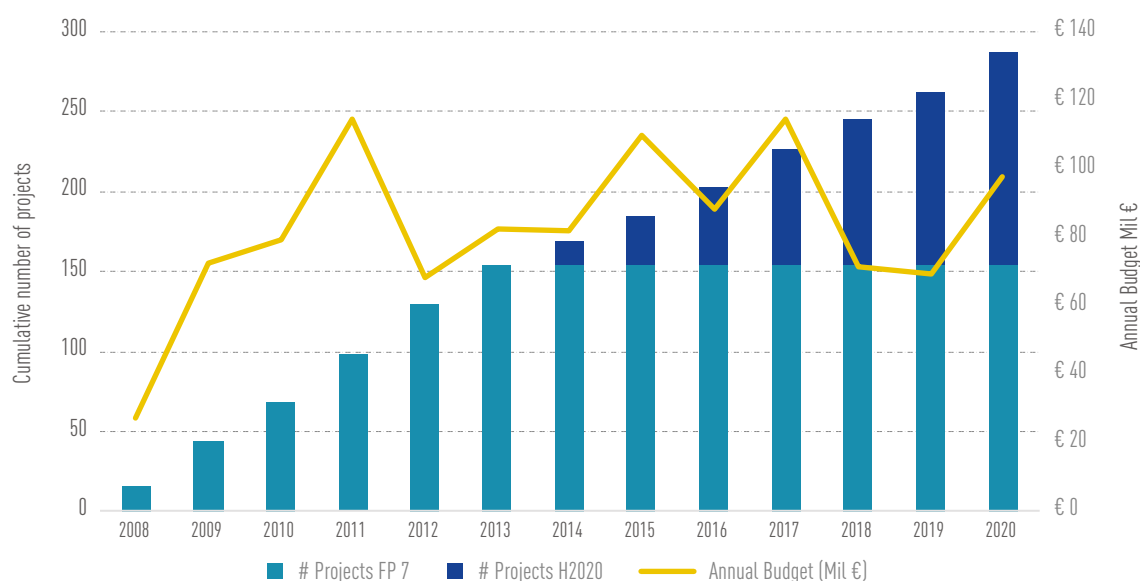
Source: Clean Hydrogen JU

4.3. HORIZON EUROPE

Under the Horizon Europe Programme, the FCH 2 JU was continued by the Clean Hydrogen JU, inheriting the technological achievements and funding expenditures of the previous Programmes. The cumulative budget invested in the projects supported by the FCH JU & FCH 2 JU programmes (154 under FP7 and 133 under Horizon 2020) per year per fund origin is displayed in Figure 8.

21. RIA is combined with CSA, as the H2020 MAWP did not foresee separate CSA actions.

Figure 8: Number of Clean Hydrogen JU supported projects and annual budget calls 2008-2020.



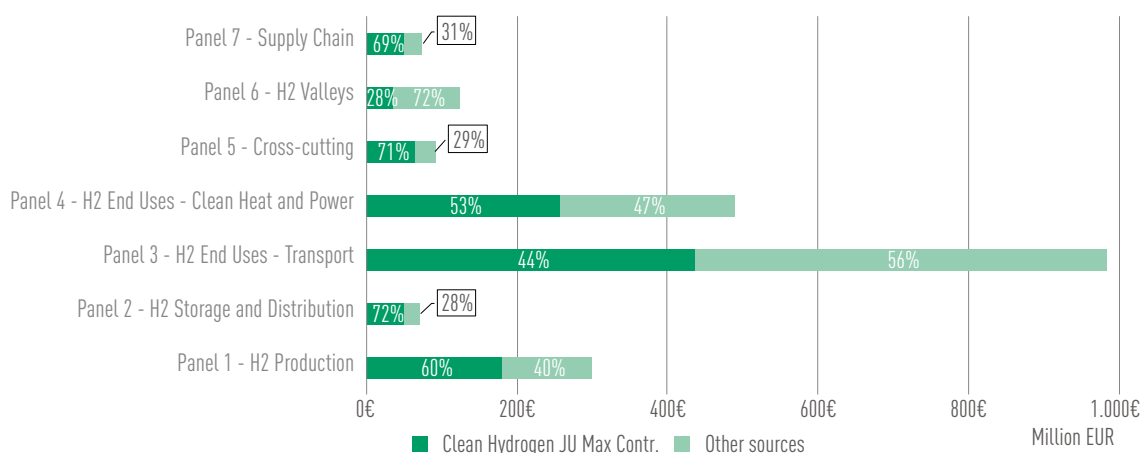
Source: Clean Hydrogen JU

Due to the different structure of the Clean Hydrogen JU Programme compared to its predecessors, the previous projects were redistributed to the seven Pillars of the new Programme as follows:

- Pillar 1: Hydrogen Production: 56 projects
- Pillar 2: Hydrogen storage and distribution: 21 projects
- Pillar 3: Hydrogen end uses – transport: 67 projects
- Pillar 4: Hydrogen end uses – clean heat and power: 77 projects
- Pillar 5: Cross-cutting Issues: 46 projects
- Pillar 6: Hydrogen Valleys: 3 projects
- Pillar 7: Hydrogen Supply Chains: 17 projects

The total cost of projects supported by the predecessors of the Clean Hydrogen JU so far is presented in an aggregate form in Figure 9.

Figure 9: Percentage of total funds contributed by Clean Hydrogen JU and other entities.

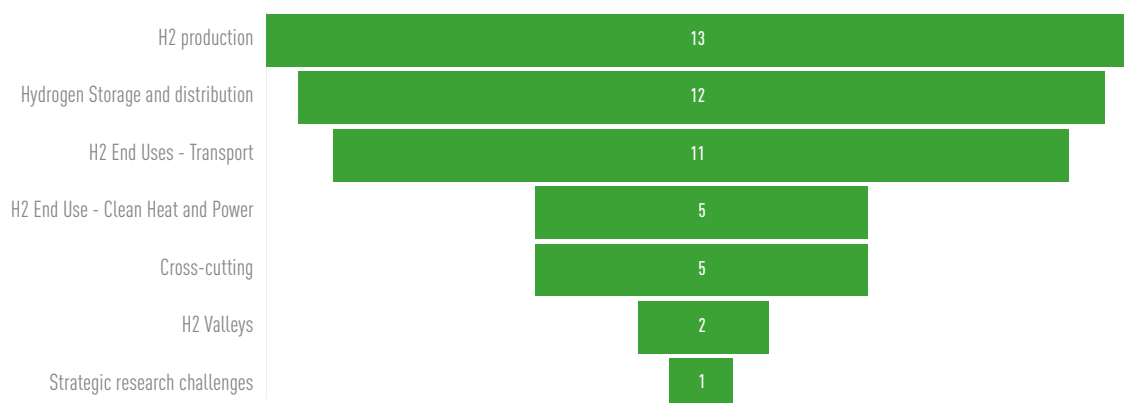


Source: Clean Hydrogen JU

The Clean Hydrogen JU published the 2022 Call for Proposals for a foreseen total budget of EUR 300.5 million²². The Call addresses key strategic priorities as identified by the members of the Clean Hydrogen JU, considering the views of the wider scientific community and relevant stakeholders. It encompasses different areas of research and innovation within the objectives of the Clean Hydrogen JU.

A total of 41 topics were part of the call for proposals, considering the objectives of each of the Pillars. In particular, the topics concern 10 for Renewable Hydrogen Production, 11 for Hydrogen Storage and distribution, 8 for Transport and 4 for Heat and Power. In addition, 5 topics will support Cross-cutting activities, 2 will support Hydrogen Valleys and 1 a Strategic Research Challenge. These are visualized below in Figure 10.

Figure 10: Call 2022 maximum number of projects per Pillar expected to be funded.

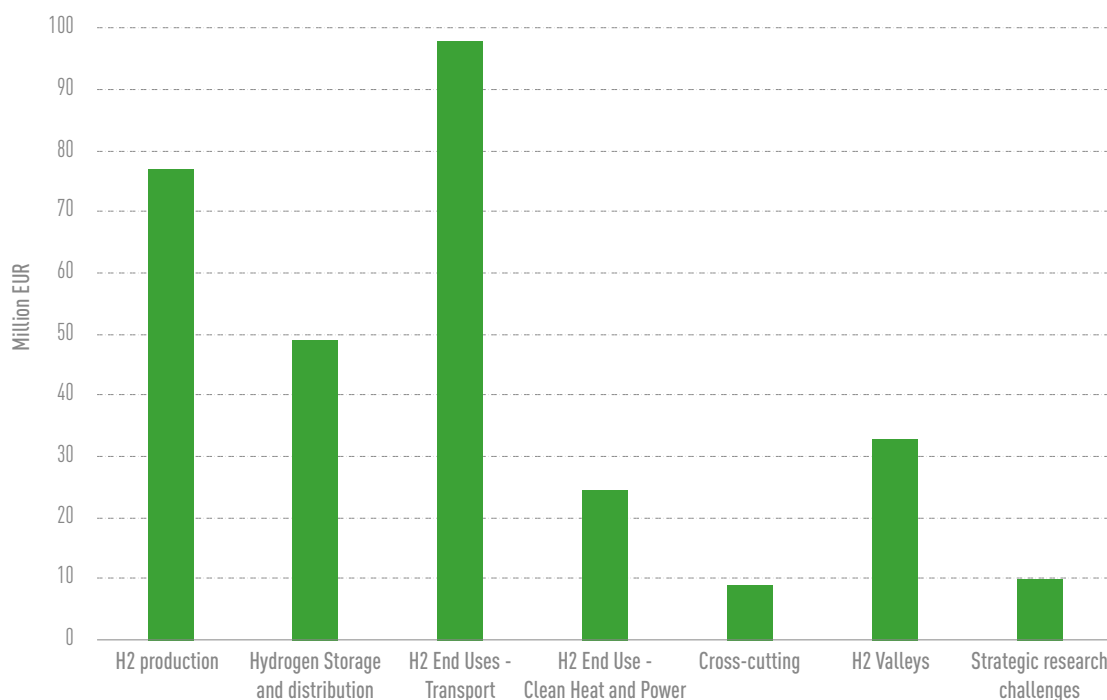


Source: Clean Hydrogen JU

The foreseen total budget of EUR 300.5 million for the 2022 Call will be allocated per Pillar as follows, presented in Figure 11.

22. The proposals for Call 2022 do not mean that the relevant amount will necessary be signed, as this depends on the evaluation and the final GAPs to be signed.

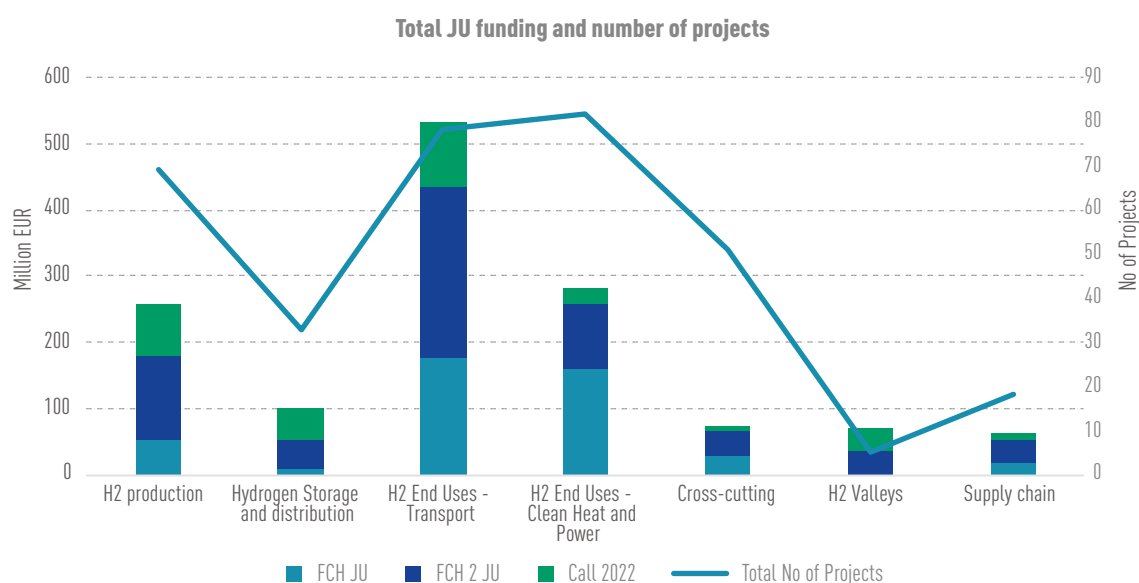
Figure 11: Clean Hydrogen JU Call 2022 maximum budget allocation per SRIA Pillar



Source: Clean Hydrogen JU

Combined with the previous Programmes, the budget allocation across all Programmes can be visualised as follows.

Figure 12: Total JU funding per Pillar and total number of Programmes, including Call 2022²³

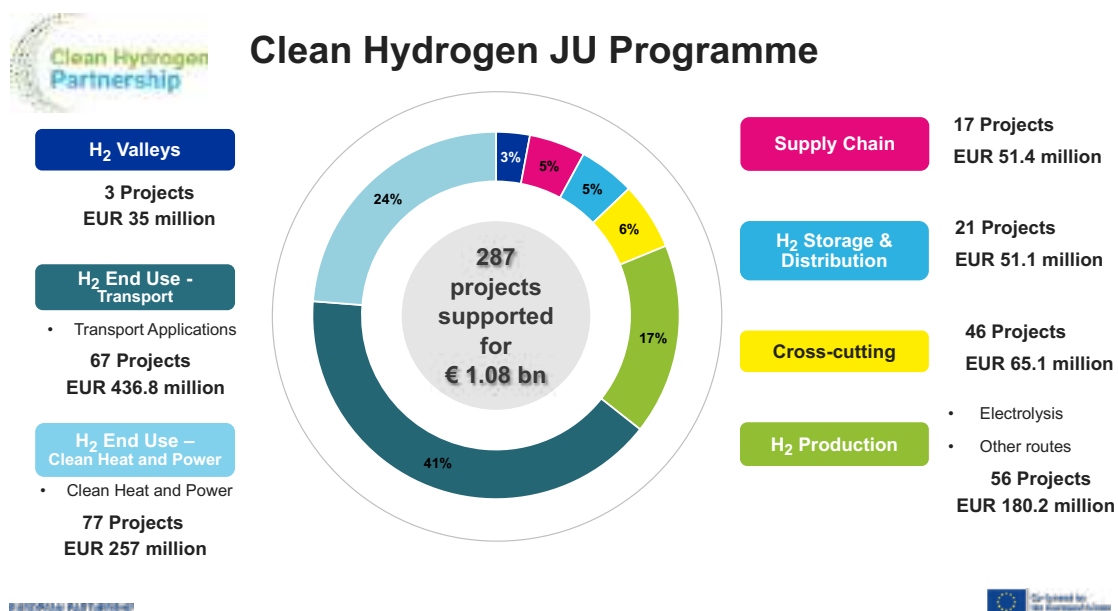


Source: Clean Hydrogen JU

23. The actual funding amount and number of projects in relation to Call 2022 depends on the final evaluation of the proposals for each Topic and the signing or not of the relevant grants.

In summary and excluding the Call 2022 as the relevant grants have not been signed yet, the overall split of the Clean Hydrogen JU funding can be summarised in Figure 13.

Figure 13: Overall structure of the Clean Hydrogen JU programme and the Pillars for the current review (project call years 2008 – 2020).



Source: Clean Hydrogen JU

05. PILLARS REVIEW

5.1. PILLAR 1 - HYDROGEN PRODUCTION

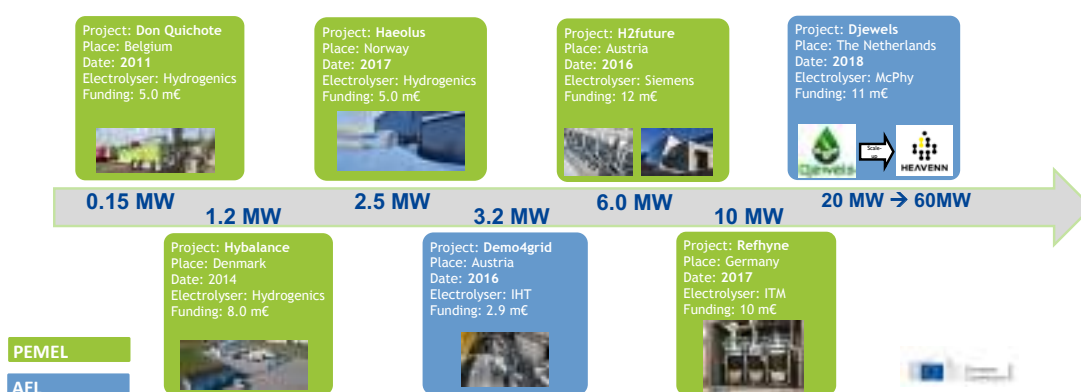
Hydrogen produced and used in the EU (and globally) is largely produced from fossil fuels. Hydrogen will play its role as an energy vector in a decarbonised society only if production through sustainable methods on a large scale is feasible; hydrogen technologies need to be scaled up similarly to the way this was done for renewable technologies during the last decade. According to the SRIA²⁴ this can be feasible only with cost-competitive renewable hydrogen; in transport applications, a cost around 5 €/kg²⁵ at the pump must be achieved for cost parity with conventional fuels²⁶. In industry, renewable hydrogen as a feedstock²⁷ must reach levels between 2-3 €/kg to achieve cost-parity with fossil-based inputs, once the cost of carbon is included in the feedstock cost.

The projects in Pillar 1 contribute towards achieving the techno-economic objective of making hydrogen production from renewables competitive and enabling the scale-up of these technologies. Improvements in efficiency and cost reduction are required across all hydrogen production routes.

Low-Temperature Electrolysis: For both Alkaline and PEM electrolyzers, the projects have focused on three main features that the electrolyzers should develop, showing significant progress:

- (a) provide reliable green hydrogen production solutions to decarbonise industrial processes, like steel plants (H2FUTURE), refineries (REFHYNE) and food industries (DEMO4GRID);
- (b) achieve a rapid response time (in the order of a few seconds) to participate in the primary and secondary grid balancing markets, demonstrated by DEMO4GRID, H2FUTURE and REFHYNE;
- (c) upscale the electrolyzers to a multi-MW level, with demonstration projects exhibiting in 10 years a significant increase of electrolyser capacity (Figure 14), while in parallel reducing the required funding per MW of electrolyser installed, that is due to economies of scale, increased commitment from beneficiaries and reduction in CAPEX.

Figure 14: Upscaling low temperature electrolyser capacity over the life of the JU.



24. Before the observed increase in energy prices.

25. This can be further lowered though through the aid of the recently proposed ETS-2 and some of the new measures included in the revision of the Effort Sharing Decision.

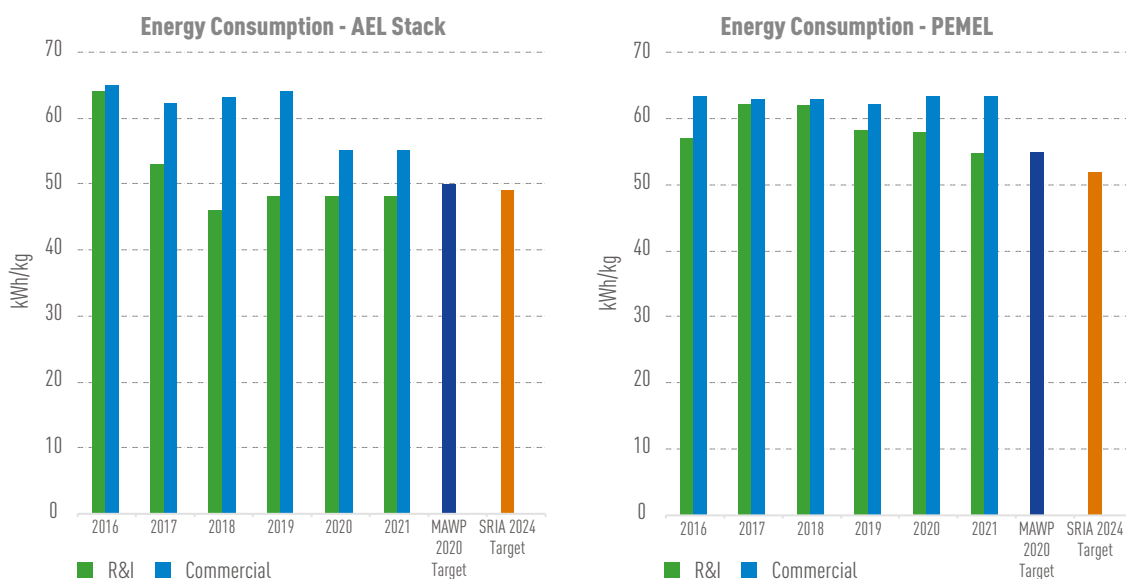
26. See Figure 15 in [Strategic Research and Innovation Agenda](#) of Hydrogen Europe / Hydrogen Europe Research.

27. Green Hydrogen Cost Reduction: Scaling up electrolyzers to meet the 1.5°C climate Goal, IRENA 2020.

Source: EU Hydrogen Research Days including Programme Review, 27-28 October 2022

Moreover, the R&I projects funded by the JU have contributed to improving a number of techno-economic parameters of the low temperature electrolyzers, most importantly reaching all the MAWP 2020 targets for PEM electrolyzers. The improvement in terms of energy consumption both for AEL and PEMEL is depicted in Figure 15 below, comparing also the annual achievements of the R&I electrolyzers versus the commercial ones, which are the ones used in the HRS projects.²⁸

Figure 15: Energy consumption between R&I and Commercial projects of both Alkaline and PEM electrolyzers



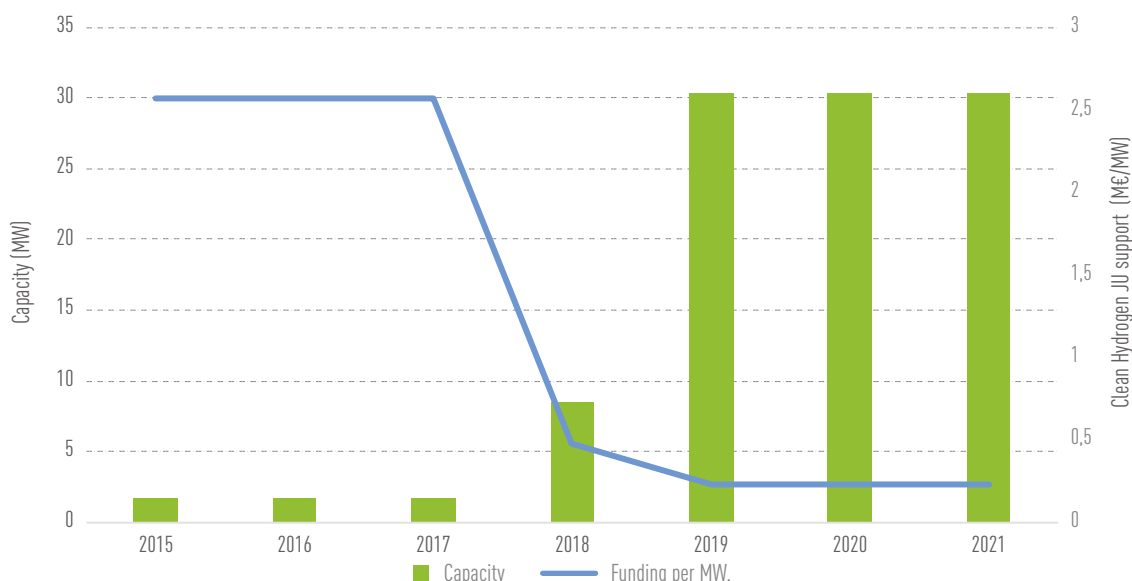
Source: EU Hydrogen Research Days including Programme Review, 27-28 October 2022

AEMEL is currently at a low TRL level and cannot presently achieve the performance and durability of other water electrolysis technologies. The Clean Hydrogen JU with the Call FCH-02-4-2019 “New Anion Exchange Membrane Electrolyzers” approved and funded three projects (CHANNEL, ANIONE and NEWELY) to provide the material and design breakthroughs necessary for this technology to fulfil its potential. In general, they managed to achieve most of their goals at the component level, with promising data on novel membranes, electrocatalysts and combined as Membrane Electrode Assemblies (MEA), raising expectations for further exploitation if the materials developed can show enhanced performance and durability, when functioning in the short-stack format.

High-Temperature Electrolysis: This Research Area covers mainly the SOEL technology. The EU appears to be maintaining a leading role with the development and commercialisation of SOEL, with both low and high TRL projects. Significant progress against most technical KPIs appears to have been made in the previous programme. Several projects are currently at a relatively early stage, but the Clean Hydrogen JU overall funding in HT electrolysis compared to the number of installed R&I MW is decreasing demonstrating the progress already made, as shown in Figure 16.

28. Commercial projects refer to data coming from transport projects using commercial electrolyzers for the production of hydrogen for their HRS. The bars indicate the best values reported per year (not the best value up until that year). Note also that almost in all cases there were better values than the ones depicted in the graphs, but which cannot be reported due to confidentiality reasons. Finally, in some cases the values do not come from one project, but are the result of averaging, to respect the confidentiality aspects.

Figure 16: Evolution of high temperature electrolysis funding per MW.



Source: EU Hydrogen Research Days including Programme Review, 27-28 October 2022

Reversibility of SOEL technology is technically interesting: when renewable energy is available the system produces green hydrogen as an electrolyser but can also generate electricity in a reverse fuel cell (SOFC) mode (project SWITCH). It can also contribute to improve energy efficiency using the waste heat in industrial processes (GrInHy2.0, MULTIPLHY). However, reversibility does not seem to be fully justified so far by the use cases.

Also, PCCEL technology is presented by the project GAMER, under the call topic *FCH-02-2-2017: Game changer High Temperature Steam Electrolysers*. It has advanced tubular PCEL technology and is currently building a 10kW system, however the high degradation rates prevented the scaling up so far. The project published its findings in *Nature Materials*²⁹.

Many new electrolysers are currently in operation under Clean Hydrogen JU projects, demonstrating business cases suitable for different type of industries (refineries, steel making etc) and ancillary services:

- A 3.2 MW pressurised AEL in Austria is commercially setup and demonstrated in March 2022 under the project **DEMO4GRID**³⁰ to provide hydrogen (for heavy-duty vehicles), heat and grid balancing services.
- A 2.5 MW PEMEL, directly connected with a 45 MW wind farm in a remote area of Norway started operation officially in June 2022. **HAELUS** project can produce up to 1 tonne of hydrogen a day (at 30 bar and 60°C) and is combined with a storage tank and a 120 kW fuel cell for re-electrification. The project achieved the targets for electrolyser efficiency and cost per kW.
- A 6 MW PEM electrolyser system installed at the Voestalpine steel plant in Linz in 2019 by the project **H2FUTURE**, providing also grid balancing services. The installation achieved a stack efficiency target up to 83%, and an operational range of 17-100%. The target production rate of 1,200 Nm³/h was reached. Due to the ancillary services, H₂ production costs are reduced by 25-45%.
- A 10 MW PEM electrolyser from ITM is operating since the beginning of 2022 in the Shell Rhineland Refinery in Wesseling, Germany, by the project **REFHYNE**. It supplies the refinery with 4,000 kg of green hydrogen a day (at 20 bar pressure). Based on the experience, a new 100 MW installation is being considered.

29. Vøllestad, E., Strandbakke, R., Tarach, M. *et al.* Mixed proton and electron conducting double perovskite anodes for stable and efficient tubular proton ceramic electrolysers. *Nat. Mater.* **18**, 752–759 (2019). <https://doi.org/10.1038/s41563-019-0388-2>.

30. It is building on the outcomes of the ELYGRID and ELYNTEGRATION projects

- Two “game changer” projects were supported aiming for PEM electrolyzers operating at high pressures and current densities. The **NEPTUNE** project reached individual targets (single cell operation at 4 or even 8 A/cm², reaching 100 bar at stack level), but did not manage to reach all targets at the same time at stack level.
- Also, the **PRETZEL** project developed cost-efficient Vacuum Plasma Spray Systems (VPS), coated bi-polar plates, and Porous Transfer Layer (PTL) which were tested up to 6 A/cm² and showed a cell efficiency of 77% at a 25 kW stack. Stable high-pressure operation was achieved at 75 bar, and higher-pressure levels seem feasible. Moreover, GKN manufactured novel porous current distributors (PCD) by sintering a titanium powder micro porous layer onto titanium expanded metal sheets, increasing PEMEL efficiency very significantly by over 20% at 4 A/cm² compared to state-of-the-art mesh type PCDs³¹. The Ti-GKN PCD component was publicised and commercialised and is now available as a product, sparking the interest of several potential customers.
- The world’s biggest HT SOEL at a capacity of 720 kW is demonstrated since August 2021 by the project **GrInHy2.0**. The installation uses steam coming from industrial waste heat at a Salzgitter steel mill. The production rate capacity has been increased to the full capacity of 18 kg H₂/h, having achieved also the target of 84% of lower heating value (LHV) efficiency and investment cost below 4,500 €/kgH₂/d. In parallel the project conducted long-term stack testing which will be continued in the follow-up MULTIPLHY project.

Other Routes of Renewable H₂ Production: Compared to electrolysis, all other renewable hydrogen production technologies are of lower TRL. The JU is supporting alternative routes to electrolysis for renewable hydrogen production for example project **BIOROBURPLUS** in reforming of CO₂-containing biogas and **HYDROSOL-BEYOND** in demonstrating solar thermochemical hydrogen production, that is facing a number of technical challenges regarding the durability and stability of the materials operating at temperature over 1,000°C.

GAP ANALYSIS – MAIN JRC RECOMMENDATIONS

As large-scale deployment can be expected under other programmes, such as the hydrogen Important Projects of Common European Interest (IPCEI), the focus should be on areas of clear added value. This should include both lower TRL research that will develop the next generation of hydrogen production technologies and selected demonstrations, that should focus on first of a kind deployment in applications that can assist the rapid deployment in industry.

LT Electrolysis: There are still areas where the Clean Hydrogen Joint Undertaking will be able to play a vital role by demonstrating the value of renewable hydrogen. Also, identifying or anticipating gaps and bottlenecks arising from large projects in programmes such as the hydrogen IPCEI will be crucial. The most beneficial focus areas may be in flexible operation, when considering an overall ecosystem approach focussing on the interaction with flexible loads, grid balancing etc. Also, the development of novel manufacturing methods for the automation of electrolyser manufacture is critical, as a great deal of them is currently manually performed.

At the lower TRL level, there is already focus on improved materials and components for next generation PEMEL and AEMEL electrolyzers. This could also be extended to AEL, where the last programme did not lead to the improvement of the fundamental MAWP KPIs for this technology. In general, there should be a focus on reduction in critical raw materials and the achievement of high current densities without the use of platinum group metals (PGM), in particular iridium in PEMEL. Where this cannot be achieved, a greater focus on recycling methods could be applied. Alternatives to Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS) containing membranes should also be developed.

For AEMEL, the current projects are developing stacks to the size of 2 kW. The projects seem to be highly successful in developing novel materials and components so the next focus should be on scale up to more practical stack and system sizes.

31. According to tests performed at DLR

It has been observed that many of the game changer, low TRL, projects have issues in achieving operating hours at the final stack or short-stack sizes, usually due to the materials and component research phase of the project overrunning. An alternative approach may be to have a larger number of shorter projects (e.g. 2 years) developing novel materials, and only the most successful progressing to one year of scale up (e.g. 2 out of 4 projects). This could also increase the degree of urgency.

Finally, as mentioned in the SRIA, the focus on new technologies for seawater electrolysis could become increasingly important for the future.

HT Electrolysis: With SOEL being at a lower TRL level (and system scale) than PEMEL and AEL, there will certainly remain some opportunities for larger scale demonstrations and integration in industrial settings within the Clean Hydrogen JU programme. There is still considerable room for improvement in both technical and economic KPIs associated with the technology. The programme can also make a valuable contribution regarding improved, cheaper manufacturing methods for the larger scale production of SOEL cells, stacks and systems, regarding the automation of manufacturing steps.

At the lower TRL level, focus can include the reduction in use of those heavy and light rare earth metals which are listed by the European Commission as critical raw materials. The economic and ecological impact of the expanded use of these materials should be considered. Additional efforts into lowering the operating temperature and increasing output pressure of the hydrogen produced should be made.

Additional resources to improve durability of SOEL coupled to intermittent RES could be allocated if considered of more added value compared to the focus on reversible electrolysis, for which it is not clear if it corresponds to industry/customer needs.

Regarding PCCEL, the project GAMER seems to have been very successful, so important to follow this up, with a project that includes scaling up and consideration of manufacturing methods.

Alternative Methods of Hydrogen Production: If biogas reforming is to be part of the portfolio of hydrogen production options, more resources are needed. Long-term testing of various technologies, like Oxidative Steam Reformers (OSRs) and Catalytic Membrane Reactors (CMRs), must be performed, following the work done by the BIONICO or BIOROBURPLUS projects, to clarify if this approach has the potential to reach the cost and efficiency targets, or if it can in general compete with water electrolysis to produce green hydrogen. The actual R&D work required must also make sure to be reflected in the SRIA/MAWP targets.

Despite the significant investment made so far to develop alternative hydrogen production routes, none of them, at present, have reached a maturity level for long-term, large-scale demonstrations. Often these projects do not have collaborations beyond those with the same topic, and at a similar (low) level of maturity. It could be beneficial if they could collaborate with projects at a higher TRL level that could assist with the scale-up step that seems to be an issue for many of these projects.

Whereas the production of hydrogen from biomass or waste is a low carbon option, it is not obvious that these routes make sense both from economic and environmental perspective. It is proposed to fund a new study, comparing the various alternative hydrogen production methods in terms of cost and environmental impacts. In addition, the current TRL of each route should be assessed carefully. This could be an update of the study funded by FCH JU in 2015, analysing eleven different pathways.

For solar thermal hydrogen production, there are no technical targets in the SRIA, except an overarching KPI for hydrogen production rate. This would imply that the MAWP targets have been achieved, but it is not yet clear if the HYDROSOL-BEYOND project will be successful. If not, the targets for this production route may have to be expanded upon, and the targets revised.

5.2. PILLAR 2 - HYDROGEN STORAGE AND DISTRIBUTION

Hydrogen storage and distribution technologies consist the cornerstone for building the necessary logistics infrastructure to store and transport hydrogen. This would ideally be from areas with large renewable potential to demand centres across Europe, as highlighted by the European Hydrogen Strategy. In parallel, the RePowerEU plan envisions the import of 10 million tonnes of hydrogen by 2030. There are various options to transport and store hydrogen, with the SRIA calling for a pluralistic approach with respect to the technologies to be investigated and supported. This is in line with a recently published JRC Technical Report³² supporting that there is no single optimal hydrogen delivery solution across every transport scenario. The most cost-effective way to deliver renewable hydrogen depends on distance, amount, final use, and whether there is infrastructure already available. Therefore, a number of technologies need to be developed, which will then be used to serve as building blocks of the EU-wide (and global) logistical infrastructure.

Aboveground Storage: Hydrogen can be stored as compressed gas in aboveground pipelines or other types of pressure vessels³³. Solid state hydrogen storage is one of the technologies funded by the Clean Hydrogen JU (HYPER, BOR4STORE, EDEN) which has certain advantages for aboveground storage. Metal or chemical hydrides allow hydrogen storage at high volumetric and gravimetric density at low pressures. There has been a lot of research effort, also by many projects funded through other programmes at (inter)national and EU level, to identify and develop materials with the right characteristics for this purpose. Cyclability and thermal management have proven to be particularly challenging.

Clean Hydrogen JU is putting effort to improve and advance innovative technology for solid state hydrogen storage, demonstrating at reasonably large scale, which is good progress compared to predecessor projects. Research should focus to enable a lifetime of the system of 10-20 years, testing materials that can withstand thousands of cycles for stationary storage. Moreover, a thorough techno-economic assessment is needed before further investment into solid state storage systems, as it is possible that it cannot be competitive with compressed gas solutions, for most applications.

Underground Hydrogen Storage: Low-cost bulk storage solutions are necessary to buffer any mismatches between demand and consumption of hydrogen production powered from renewables. Underground storage³⁴ offers the potential to deploy large amounts of gas storage at a low cost. Fully exploiting the available geological resources, to take advantage of a relatively widespread options on European territory, requires further research efforts. Clean Hydrogen JU is funding a project to test hydrogen storage cycles in a salt cavern (HYPSTER) and other two projects assessing the feasibility of large-scale underground storage in porous reservoirs in Europe (HYSTORIES and HyUsPre).

H₂ in the natural gas grid: This research area focuses on admixture of hydrogen to natural gas and repurposing of natural gas pipelines for the transmission and distribution of 100% hydrogen.

Liquid H₂ carriers: Hydrogen delivery at large scales and over long distances is deemed challenging, due to the low energy density of hydrogen. Apart from Liquid Hydrogen (LH₂)³⁵, hydrogen carriers are an important component for establishing a hydrogen delivery chain. The chemical carriers being considered by stakeholders are ammonia, methanol and Liquid Organic Hydrogen Carriers (LOHC). Ammonia production (with fossil fuels) and transport can be considered established technologies, but there is not much experience yet with its cracking (hydrogen release) at scale. Unlike methanol, LOHC does not release CO₂ during hydrogen release and in addition it has the advantage that existing infrastructure such as oil tankers can be reused. A critical parameter for

32. Ortiz Cebolla, R., Dolci, F. and Weidner Ronnefeld, E., Assessment of hydrogen delivery options, EUR 31199 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-56421-8, doi:10.2760/869085, JRC130442.

33. Since mid-1960s, the two largest liquefied hydrogen storage tanks (around 212 tonnes of liquefied hydrogen each) have been operating at NASA facilities.

34. There are salt caverns commercially operating for the storage of hydrogen in the U.K. and U.S. In Teeside, U.K. three smaller caverns of 70 000 m³ capacity are owned by Sabic Petrochemicals. In Texas, three larger caverns, with capacity over 560 000 m³ each are supplying hydrogen to the petrochemical industry (operated by Praxair, Air Liquide and ConocoPhillips).

35. LH₂, due to its high gravimetric and volumetric density is a promising option for hydrogen transport, but there are still numerous technical issues to be overcome, such as reducing the energy demand for liquefaction and boil off management.

the delivery of hydrogen with chemical carriers is the energy needed for dehydrogenation³⁶. EU still has some catching up to do, as Japan seems to have advanced LOHC delivery to a higher TRL.

Compression, purification and metering solutions: Compressors are critical for the delivery of hydrogen, with pressures above 700 bar required for refuelling and up to 100 bar for injection into pipelines. Higher reliability must be achieved especially for HRS; work is on-going in the COSMHYC XL and COSMHYC DEMO projects³⁷.

Separation and purification of hydrogen can be carried out through Pressure Swing Adsorption (PSA), membrane separation, cryogenic separation/partial condensation, electrochemical separation or hybrid solutions. Research is being conducted to improve processes for both purification and separation of hydrogen, mainly in terms of energy efficiency and costs. One of the objectives is the separation of hydrogen from hydrogen and natural gas blends with low hydrogen content (up to 20%). For large hydrogen volumes, typically PSA is used. This process can produce purities up to 99.999% H₂, but this may entail low hydrogen recovery rates (up to 65-90%), depending on the feed pressure. Diffusion based techniques utilizing 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 purification has been targeted by the projects HY2SEPS2 and MEMPHYS, which have been developing proof-of-concepts for separation and purification systems. The Hy2Seps-2 project developed and tested hybrid separation schemes combining Membrane and PSA technology for the purification of hydrogen from a reformat stream. The projects focused on structured adsorbents for PSA based on Metal Organic Frameworks (MOFs). Finally, the MEMPHYS project focused on electrochemical separation, and achieved its target for energy consumption (3 kWh/kg H₂). Research was conducted on alternative catalysts to improve tolerance against toxins. Diagnostics were used to understand the water management in the cell and causes for cell failure.

H₂ Refuelling Stations: The deployment of HRS is expanding globally. In 2021, 142 HRS went into operation worldwide, more than ever before. In total, 685 HRS were in operation worldwide at the end of 2021, of which 363 were in Asia, 86 in North America and 228 in Europe. Germany is the country with most operating stations in Europe (101), followed by France (41), the UK (19), Switzerland (12) and the Netherlands (11)³⁸.

The geographical coverage of hydrogen refuelling infrastructure continues to expand, supporting the increasing number of FCEVs deployed. Currently, 177 hydrogen-refuelling stations are sending live data. The EU HRS availability system³⁹, an initiative funded by the Clean Hydrogen JU, offers a portal providing live-status information regarding each HRS in Europe, as shown in Figure 17.

The average HRS availability in 2021 for cars was 89% and for buses 97%, the latter surpassing the MAWP 2020 target (96%), but also on track to meet the SRIA 2024 target of 98%. The major causes for station downtime were the compressor, scheduled maintenance and updates.

36. For most LOHC systems, the enthalpy of the de-hydrogenation reaction is > 60 kJ/molH₂. More energy is needed for hydrogen compression and purification, and to run the balance of plant systems. However, most of the energy could be supplied in the form of heat, which makes this delivery option attractive if there is a suitable source of waste heat.

37. See also the following section on HRS.

38. H2 stations [press release](#), February 1st 2022

39. <https://h2-map.eu/>

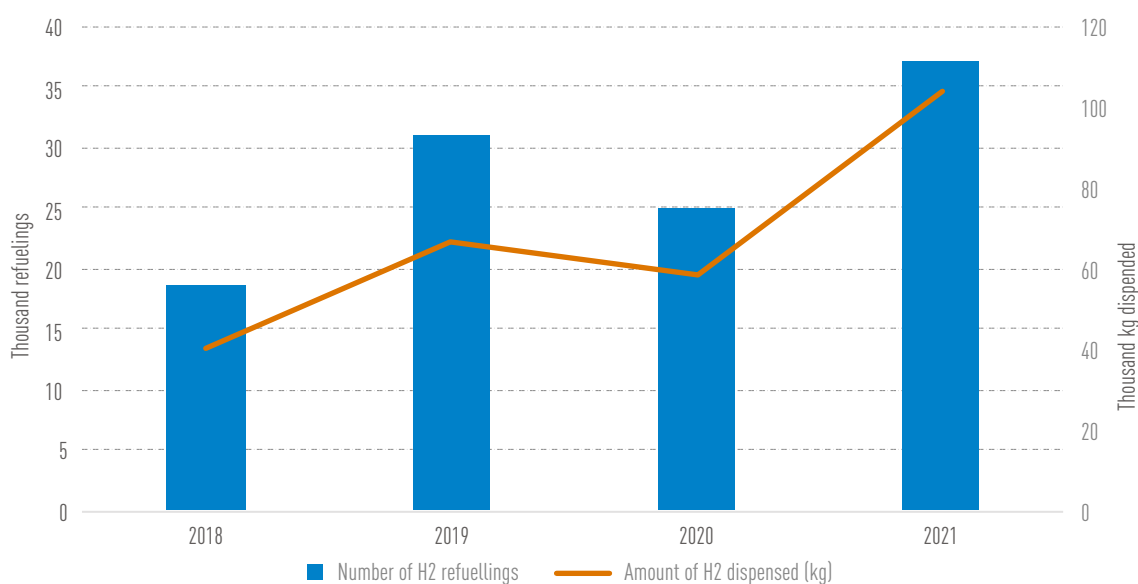
Figure 17: Availability date from the HRS Availability Map



Source: HRS Availability Map (snapshot 25.10.2022)

Figure 18 shows the number of H₂ refuellings for cars and the quantity of H₂ dispensed between 2018 and 2021. Apart from the Covid implications that disrupted temporarily the trend in 2020, there is a significant increase in 2021 in thousands refuellings and H₂ quantities used.

Figure 18: Number of H2 refuellings for cars with the amount of H2 dispensed.



Source: Clean Hydrogen JU

H2ME reported that with the increasing number of HRS, the chiller cooling hydrogen to the level required by the fuelling protocol SAE J2601 (to which most of the FCH 2 JU stations comply), is also becoming a downtime source, indicating the importance (and challenge) to move ahead for new standards that would allow more reliable and faster HRS.

The technology progress on HRS reported above was based on car and bus demonstration projects, reviewed under Pillar 3. Changing to focus on HRS research projects, COSMHYC XL and COSMHYC DEMO under Pillar 2 focus solely on HRS development, at a lower TRL, based on the innovative scalar and modular hybrid compression solution developed under the COSMHYC project. If successfully deployed this original technology, combining a metal hydride compressor with a mechanical compressor, will enable lower CAPEX and OPEX, reduced noise, increased availability and higher hydrogen delivery efficiency. Further work is needed on improving energy consumption, mean time between failures, annual maintenance costs, labour and CAPEX of 350 bar refuelling stations for buses.

The projects under this Pillar are demonstrating significant advances in many different areas of research and innovation.

- **HyCARE** will be testing a small-scale prototype hydrogen storage tank based on solid state storage solutions, aiming for a round trip efficiency of 70%, for a total of around 40 kg of hydrogen.
- **HYSTORIES** has collated publicly available data of different types of potential porous media in Europe in a geological database. This will help to identify how many of the gas fields in Europe are likely to be suitable for hydrogen storage.
- **HYSTOC** successfully demonstrated a LOHC delivery chain in Finland of a total of 1 860 kg of hydrogen transported over 500 km. Hydrogenious is planning to commercialise the technology, using benzyltoluene (BT).
- **HYGRID** project is successful in most of its targets. The Pd-based membranes have been produced, meeting the target specifications. Carbon molecular sieve membranes (CMSM) have also been successfully tested. Very high hydrogen purities have been reached with a CMSM at lower hydrogen concentration, this seems to be the preferable option at high pressures (> 30 bar). Also, the cost target has already been met with the current system.
- The targets for cost of purification and energy consumption for separation have been reached, but not by the same project for the same technology. Therefore, more work is needed, as these targets would have to be reached together.
- The Clean Hydrogen JU has funded the installation of 113 HRS up to date (planned, deployed and decommissioned units); including cars, buses and Material Handling Vehicles (MHV) demonstration projects. The average HRS availability in 2021 for cars was 89% and for buses 97%, surpassing the MAWP 2020 target (96%), but also on track to meet the SRIA 2024 target of 98%.

GAP ANALYSIS – MAIN JRC RECOMMENDATIONS

The new programme faces a lack of on-going projects progress over the high number of KPI targets for Pillar 2 in the SRIA. However, it is positive that there are many new projects together with an increased funding.

Underground Storage: Alignment between HYSTORIES and HYUSPRE will ensure that their outcome, a full matrix of microbiological and mechanical tests able to identify the most suitable materials and conditions for storage of hydrogen in porous rock formations of the projects, will be pooled together and compared. It will be important to check the effect of operational parameters on microbiological activity in multiple types of sites, which could be a topic for a future call.

A study is recommended to determine the amount of large-scale storage that will be needed in the EU in the future, with regards to hydrogen imports. Analysing the interactions between port infrastructures, hydrogen imports and underground storage sites could be part of a future call.

Also, a clear link of all three projects to existing and future Hydrogen Valleys should be established, to ensure full utilisation of the caverns/gas fields.

LH₂ carriers: It needs to be proven whether this technology can be scaled up to be able to the level required to transport significant volumes of hydrogen, in the Mt range. Also, there are still substantial challenges to be overcome, in terms of reaction rate and cyclability. Most importantly though, the energy demand for dehydrogenation needs to be significantly reduced.

H₂ in the NG grid: It is positive that there are clear goals for the operation of gas turbines with variable NG – hydrogen mixtures (see Pillar 4), even if there are no projects yet tackling this issue. In general, the programme should carefully evaluate if hydrogen blending with NG should be pursued. Although there are some natural synergies, it might make more sense to put all effort into 100% hydrogen pipelines, whether conversion of NG pipelines or dedicated new hydrogen pipelines, rather than focusing on blending. For both 100% hydrogen pipelines and blending, the Clean Hydrogen JU should closely follow the work of the standard CEN/TC234 in order to be updated on eventual pre-normative research needs.

Compression, purification and metering: Given the number of targets for compression, more projects would be needed to address these. It is positive that the Annual Working Plan (AWP) 2022 contains a call topic for the optimisation of hydrogen compression.

The 2022 call topics are on blending/repurposing of pipelines. Road transport of LH₂ is currently not covered by any projects or call topics, except from safety perspective (Pillar 5, PRESLHY, AWP 2022 call topic). This is a concern, and it would be important for the Clean Hydrogen Partnership to prioritize these topics in the next calls.

Hydrogen Refuelling Stations: The results of the JIVE project in terms of operating HRS can be useful in view of the needs for large capacity HRS for heavy duty vehicles. As larger flows of hydrogen are dispensed for truck fuelling operations, consider funding a project on developing innovative and efficient cooling for dispensed hydrogen.

The lessons learned from the various HRS operating at present should be analysed, especially to identify any main causes of failure. Further analysis of hydrogen chillers causing downtime in hydrogen refuelling stations is recommended. In addition, the car HRS seem to have more problems than the bus HRS in terms of availability (see Pillar 3). Mean time between failures should be increased for both to reach the SRIA target of 72 days (700 bar) and 144 days (350 bar).

As regards the metal hydride compression, it is a rather pioneer technology dependent on the hydride materials performance during their whole lifetime and a high number of cycles. Any new calls for proposals should follow the assessment of the COSMHYC project results.

Finally, the SRIA has several KPI tables for hydrogen compression; it is recommended to clearly separate the targets between applications (pipelines and HRS).

5.3. PILLAR 3: HYDROGEN END-USES: TRANSPORT

The predecessor of the Clean Hydrogen JU, the FCH JU, dedicated significant effort to develop, validate and demonstrate technologies for FC material handling vehicles, FC buses and FCEV passenger cars that can be considered ready for market deployment. Still, solutions in sectors such as heavy-duty vehicles, off-road and industrial vehicles, trains, shipping and aviation need further development and demonstration. Pillar 3 encompasses both research projects and demonstration initiatives to fulfil these objectives and is divided into seven research areas: FC stack and FC system technology, on board hydrogen storage, heavy duty vehicles, waterborne applications, rail applications, aviation, buses, coaches and cars.

Fuel cell stack and fuel cell system technology: Although there are currently available commercial PEM FC systems for transport and stationary applications, their durability requires further improvement. Loss of

performance of FC systems is still a bottleneck in wide dissemination of hydrogen fuel cells in industry and transport. Another difficulty constraining broad application of PEM FC technology corresponds to usage of expensive and rare materials, mainly PGM metals. There is a continuous challenge to maintain satisfactory degradation rate of FC stack with minimising use of PGM materials. The low PGM loading catalysts are able to provide very good performance at beginning of the life, but degradation rates for such low PGM loading materials is still unsatisfactory and needs development.

On-board vehicle hydrogen storage: Compressed hydrogen storage on-board vehicle technology is already well established. State-of-art compressed hydrogen storage systems are made up of carbon fibre composite reinforced vessels. A key question is the decrease of tank's costs by reducing the amount of carbon fibre used while keeping the storage's performance and safety. An important technological progress is the development of conformable tanks, which will allow optimising the volume of hydrogen stored by adapting the tank shapes to the available free space in the vehicle. Liquid cryogenic hydrogen is envisaged as a solution to store large amounts of hydrogen in heavy duty vehicles and maritime vessels as well as in future rail and aeronautic applications.

Heavy duty vehicles: Fuel cell and hydrogen trucks are considered one of the best options to decarbonise heavy duty road freight transport. Fuel cell trucks (FCT) are potentially best suited for longer-range missions and the heaviest goods, enabling connectivity to more remote areas than other solutions such as battery or catenary trucks⁴⁰. Figure 19 highlights the countries where deployment of long-haul trucks (H2Haul project) and garbage trucks (REVIVE project) will take place.

Figure 19: Countries with expected deployment of long-haul and garbage trucks the coming years.



Source: EU Hydrogen Research Days including Programme Review, 27-28 October 2022

Waterborne applications: In Europe several projects that aim to demonstrate fuel cell powered vessels are on-going⁴¹. Bunkering of hydrogen (or ammonia) is to be developed together with fuel cell ships. The bunkering technology has to be adapted to both liquid and compressed hydrogen and there are some pilot initiatives for

40. Decarbonisation of heavy duty transport: zero emissions heavy goods vehicles, JRC, 2021

41. In the Clean Hydrogen JU project MARANDA the PEMFC is fed with hydrogen while ShipFC use ammonia and SOFC. At present there are not commercial fuel cell ships, however a number of projects are demonstrating the use of hydrogen (both compressed and liquefied) in ferries and ships. The vessels for FLAGSHIPS and HySHIP Clean Hydrogen JU projects are being built and FLAGSHIPS demonstration activities will begin in 2022.

hydrogen supply in ports have been launched⁴². There is a strong trend towards larger vessels and hydrogen delivery by ships, as shown in Figure 20. Demonstration projects are important to speed up standards for waterborne applications.

Figure 20: Towards larger vessels and H₂ delivery by ships



Source: EU Hydrogen Research Days including Programme Review, 27-28 October 2022

Rail applications: The hydrogen and fuel cell technology for rail applications has been trialed across Europe, Asia, North America, the Middle East, Africa and the Caribbean since 2005⁴³. Although those trials show that FCH technology can meet the requirement for rail applications, there are few demonstration projects of hydrogen train prototypes.

Aeronautic applications: At present there are some initiatives developing aircraft prototypes powered with fuel cells such as ZeroAvia⁴⁴ and the on-going Clean Hydrogen JU project HEAVEN⁴⁵. AIRBUS is working on different airplane concepts⁴⁶, where hydrogen is stored liquid and fed in hybrid turbo-fan or turbo-prop engines. The "Hydrogen powered aviation" study⁴⁷ concluded that hydrogen – as a primary energy source for propulsion, either for fuel cells, direct burn in thermal (gas turbine) engines or as a building block for synthetic liquid fuels – could feasibly power aircraft with entry into service by 2035 for short-range aircraft.

42. Project H2Ports is deploying a mobile to station refuel port's machinery and HySHIP vessel is designed to transport LH₂ for bunkering other vessels and trucks.

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

44. <https://www.zeroavia.com/>

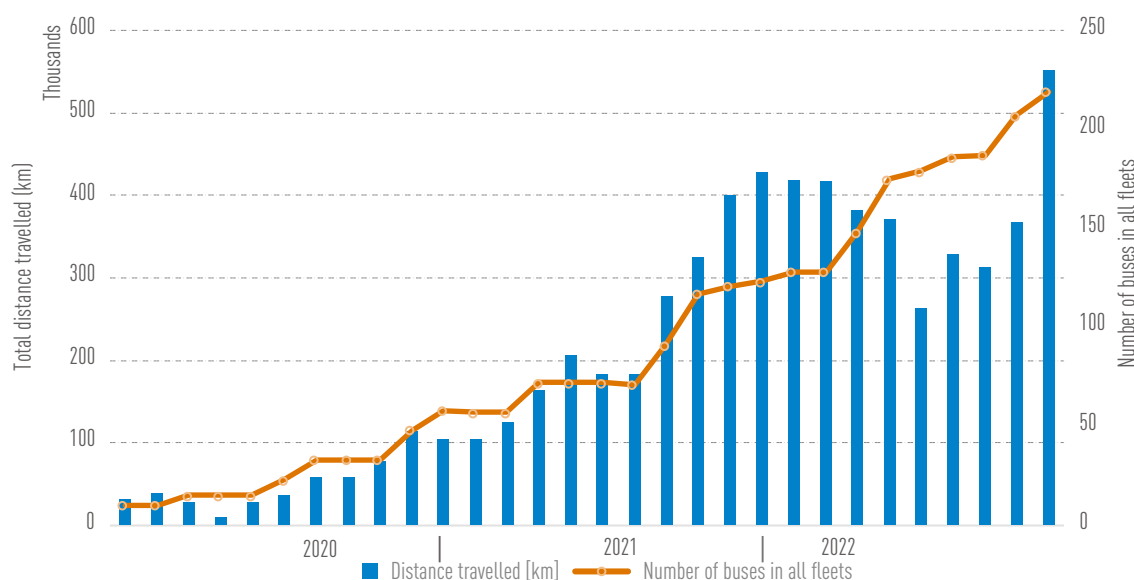
45. Before HEAVEN, HYCARUS and SUAV were pioneer FCH JU projects integrating hydrogen and fuel cells in aeronautic applications. SUAV worked on a SOFC to power a small, unmanned aviation vehicle. HYCARUS developed a PEMFC and hydrogen storage as APU for non-essential applications, which passed performance and qualification tests in a demonstrator. Unfortunately, tests could not be accomplished on-board an aircraft. Starting from HYCARUS's experience, the Clean Hydrogen JU project FLHYSAFE will use a PEMFC system as an Emergency Power Unit.

46. <https://www.airbus.com/en/innovation/zero-emission/hydrogen/zeroe>

47. **Hydrogen powered aviation:** A fact-based study of hydrogen technology, economics, and climate impact by 2050, FCH JU, 2020

Buses and cars: Fuel cell buses (FCB) are already developed by several manufacturers and successfully demonstrated. Since 2020, projects JIVE and JIVE 2 have helped to deploy 219 FCBs from European manufacturers in sixteen fleets numbering from 5 up to 50 buses each, as depicted in Figure 21. While FCBs are established, there is a need to advance the technology for longer distances to cover inter-urban and regional routes.

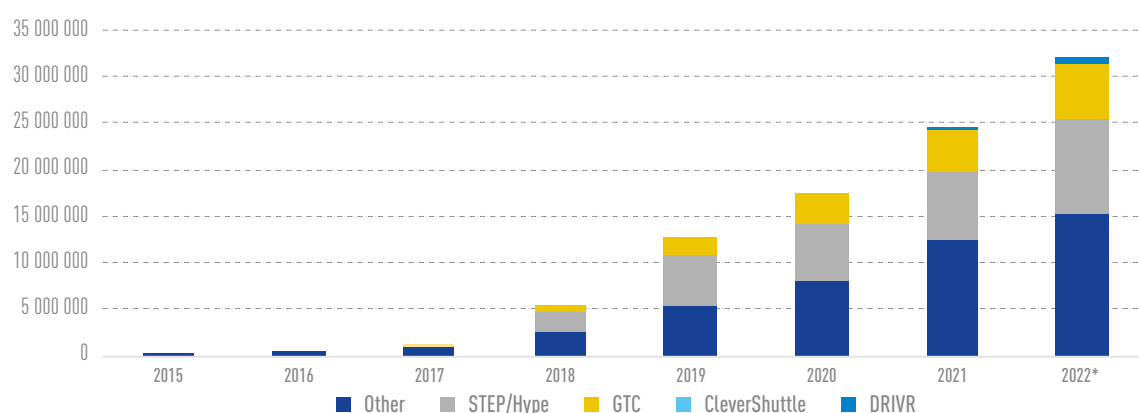
Figure 21: Total distance driven per month by buses of JIVE and JIVE 2 projects and total number of buses between 2020 to 2022.



Source: Clean Hydrogen JU

In 2021, 3092 FCEVs were in operation in EU countries⁴⁸. Figure 22 depicts the cumulative distance driven by the vehicles deployed by the H2ME, H2ME2 and ZEFER demos. In particular, the deployment of FCEV taxi fleets within H2ME 2 and ZEFER has helped to improve the business case of FCEVs and hydrogen refuelling stations.

Figure 22: Cumulative distance driven by different types of vehicles from 2015 to 2022, based on the H2ME, H2ME2 and ZEFER demos.



Source: Clean Hydrogen JU

48. More detailed statistics and evolution over time can be found in the [Fuel Cell and Hydrogen Observatory](#).

The prominent accomplishments of Clean Hydrogen JU projects under Pillar 3 in the last 18 months can be summarised as follows:

- **GAIA** managed to deliver a high Beginning of Life (BoL) power density without increasing platinum loading, reducing the Pt-specific power density from 0.45 g Pt/kW (e.g. VOLUMETRIQ) to 0.25 g Pt/kW, which is currently running a durability test to confirm the promising results.
- The composite wrapped tank with a polyethylene liner of **TAHYA** obtained an outstanding gravimetric efficiency of 6.5% setting the state-of-art and meeting Clean Hydrogen JU's SRIA target in 2024. Also, CAPEX for TAHYA is calculated at 450 EUR/kg H₂, better than SRIA target for 2024 (500 EUR/kg H₂). Finally, three patents related to the tank design and its manufacturing have been submitted.
- Four refuse FCTs (out of 14) from project **REVIVE** are already in operation and the remaining ones will be deployed in the coming months. The HRSs in Gothenburg and Groningen started operation in 2021 while Breda and Antwerp HRSs opened, respectively in April and May 2022.
- **3EMOTION** has deployed all 29 FCBs: 10 buses in London, 6 in Rotterdam and the South Holland province, 7 in Versailles, 3 in Pau and 3 in Aalborg, demonstrating the operability of buses from four different manufacturers with two different fuel cells systems. The buses are largely meeting their targets on hydrogen consumption and availability (collectively covered 741,113 km with 64.16 tonnes of hydrogen tanked).
- Combined **JIVE** and **JIVE 2** are deploying over 300 FCBs in 22 cities across Europe, the largest deployment in Europe to date. JIVE has ordered all the 142 planned buses and 121 are in operation, while JIVE 2 has ordered all 156 buses originally planned, has 98 buses in operation and expects to have the committed fleet delivered by the March 2023.
- The H2ME initiative (**H2ME** and **H2ME2** projects) is the largest European deployment to date for hydrogen mobility, planning to deploy more than 1,400 vehicles in 8 countries and 49 HRS in 6 countries. The project H2ME 2 alone has deployed 311 vehicles and 29 new HRSs in Germany, Scandinavia, France and the United Kingdom.
- The 180 FCEVs planned and already in operation (60 in Paris, 60 in London and 60 in Copenhagen) under project **ZEFER** are demonstrating viable business cases for captive fleets of FCEVs (taxi, private hire and police services).
- According to the TRUST database, the deployed 776 cars (running in 2021) drove at least 9 million kilometres (km) with a reported consumption of 96.9 tonnes of hydrogen. In total, till 2021, Clean Hydrogen JU-funded cars have driven a total of almost 29.8 million km⁴⁹ and consumed over 297.6 tonnes of hydrogen, avoiding emissions of about 2,217 tonnes of CO₂. The average 2021 fuel consumption of 1.12 kilogramme (kg) per 100 km is lower than the MAWP 2020 target (1.15 kg per 100 km) and on track to achieve the 2024 target of 1.1 kg per 100 km. The average vehicle availability exceeded 99% in 2020, which means that the expected MAWP 2020 targets for availability (98%) and fuel cell system durability (6,000 hours) have also been accomplished⁵⁰.
- The total number of Clean Hydrogen JU funded HRS is 113⁵¹ including FCEVs, FCBs and MHVs demo projects. Twenty H2ME 70 MPa refuelling stations are integrated in petrol forecourts. In 2021, 77 HRS had already been deployed (64 were reported in 2020). Some of the HRS from finished projects continue operation under the running projects (HyFIVE stations in H2ME, SWARM Zaventem in ZEFER, HYTRANSIT Kittybrewster and Frenchen HRS supporting the operation of JIVE's FCBs).

49. It is expected to increase above 35 million kms in 2022.

50. Another remarkable point for car demonstration projects in 2021 is their excellent synergies, not only limited to the sharing of findings and lessons learnt. For instance, HRSs are used by both H2ME and ZEFER, which contributed to increased utilisation at certain stations in London and Paris. Both projects also jointly disseminated their activities at certain events such as roundtables with policy makers, thus increasing impact.

51. Including 2 discontinued stations.

GAP ANALYSIS – MAIN JRC RECOMMENDATIONS

Building Blocks: The use of non-PGM for electro-catalysis is studied in the projects with encouraging results and is providing the basis to potentially reduce the use of EU defined critical raw materials. Several projects are also developing knowledge and tools to improve fuel cell designs and adapt their features to fit the requirements of automotive applications, both light and heavy duty. Recyclability of compressed hydrogen storage tanks is addressed.

To make truly cost effective and affordable PEMFCs, feasible low-PGM/PGM-free electro-catalyst alternatives and their mass adoption should be given further emphasis; this should include appropriate screening tools based on computational materials science prior to lab-scale candidate testing.

Calls for proposals should require an open access (i.e. open-source licence) to the software developed within the projects, to strengthen the shift towards open source software libraries for FC and system modelling. Also, the absence of a well-established RCS framework drive field test activities of some of the projects for storage and APU through approval from different authorities.

Heavy Duty Vehicles: At present homologation is granted following individual vehicle approval process. The overall certification process of the hydrogen vehicles is very detailed and is a source of delay in the project execution. This should be considered in future project proposals. Projects H2Haul and REVIVE shall document their experiences to help future Clean Hydrogen JU initiatives demonstrating heavy duty vehicles.

There are different alternatives for the placement of the hydrogen storage on-board heavy-duty vehicles. It is likely that more research might need to study the influence the on-board heavy duty vehicle's hydrogen storage configuration (for instance tanks that are vertically placed, systems with tanks connected by lengthy tubes or multiple conformable tanks) in their refuelling performance.

Maritime Applications: Lack of regulations and suitable standards makes difficult the approval of the vessels and the permit of hydrogen infrastructure on ports. Experience from running projects should be shared with future Clean Hydrogen JU maritime applications' initiatives. Hydrogen fuel supply and bunkering required undergoing through lengthy negotiations with supply companies.

Buses and Cars demonstration: Deployment partners have plans to scale-up their FCEVs fleets following the H2ME and ZEFER projects. Positive business cases have been demonstrated by these projects. To allow data monitoring from vehicles and HRS, ICT tools must become more reliable, as projects report issues with data loggers' performance (JIVE and JIVE2).

Overall, the potential of fuel cell and hydrogen coaches to contribute to decarbonisation of road passenger transport is high.

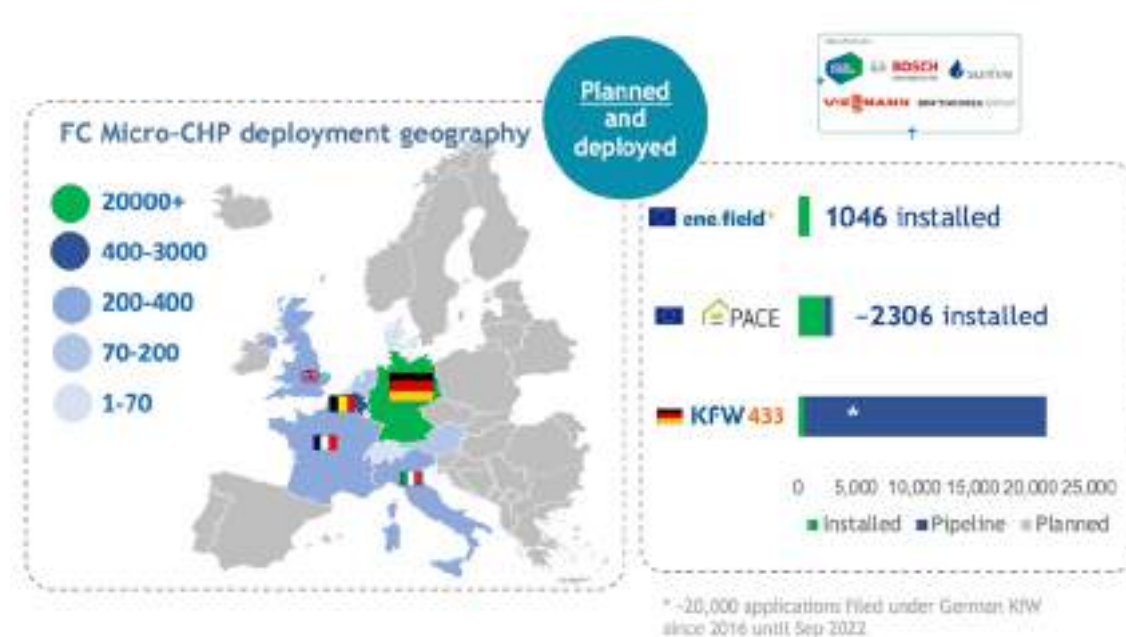
5.4. PILLAR 4: HYDROGEN END-USES: CLEAN HEAT AND POWER

The overall goal of this Pillar is to support European supply chain actors to develop a portfolio of solutions providing clean, renewable and flexible heat and power generation for all end users' needs and across all system sizes; from domestic systems all the way to large-scale power generation plants. Preferential support will be for solutions running on 100% hydrogen. However, there is still room to support solutions running on a hydrogen mixture in the gas grid (up to 20% within the context of the activities included in this support area) during the transition phase. For gas turbines, to enable a smooth transition and assure backward compatibility with conventional fuels during the transition, support for actions running with different hydrogen admixtures are likely to be required to facilitate the development process and to achieve the final goal of 100% hydrogen turbines. Stationary fuel cells, as well as gas turbines, boilers and burners are proposed to be supported according to the SRIA. Turbines, boilers and burners are new elements in SRIA.

The research areas relevant to Pillar 4 are:

m-CHP: Two projects, dealing with the use of both PEM and SOFC for micro-Cogeneration, namely PACE and OxiGEN. While OxiGEN is investigating next generation SOFC, PACE is deploying both PEMFC and SOFC in real installations, fuelled with natural gas, for fuel cell micro cogeneration for small stationary applications. PACE is a m-CHP deployment initiative involving six leading European fuel cell manufacturers, a follow-up of the FCH 2 JU project ENEFIELD. Figure 23 displays the planned and deployed fuel cells under these two projects, but also in relation to the KfW 433 programme⁵² of Germany.

Figure 23: Planning and deployment of fuel cells for domestic heat and power



Source: EU Hydrogen Research Days including Programme Review, 27-28 October 2022

Commercial Size Systems: This research area contains two demonstration projects focused on fuel cell-based systems for power and heat solutions in the mid-sized power ranges of up to 100 kW, namely ComSos and E2P2, both exploring SOFC technology. Three other projects look at the next generation systems: SO-FREE using SOFC technology, EMPOWER using high temperature PEMFC technology and CH2P looking into an innovative system prototype co-generating hydrogen, heat and electricity using Solid Oxide technology.

Industrial Size Systems: Industrial size systems include projects dealing with large scale systems, usually in the MW scale. GRASSHOPPER project addresses the challenge of setting-up a cost-effective and flexible power plant. A prototype of 100 kWe has been developed which is representative of MW scale FC plants. CLEARGENDEMO project deals with the integration and demonstration of large stationary fuel cell system (1 MWe) for distributed generation. Both projects are relying on PEMFC technology.

Off grid/back up/gensets: This Research Area contains the demonstration projects focused on off-grid applications, both in remote locations as well as for temporary power supply applications. The JRC technical assessment looked into three projects: REMOTE, ROREPOWER and EVERYWH2ERE. The projects are exploring the application of PEM Solid Oxide and Alkaline⁵³ hydrogen technologies (FC and electrolyzers) for off-grid applications, but also urban areas.

52. <https://www.kfw.de/inlandsfoerderung/Privatpersonen/Bestandsimmobilie/F%C3%B6rderprodukte/Energieeffizient-Bauen-und-Sanieren-Zuschuss-Brennstoffzelle-433/?redirect=365568>

53. For some of the electrolyzers in the Power-to-Power solutions developed in REMOTE.

Other research areas: Two projects, RUBY and WASTE2WATTS, dedicated to the use biogas for SOFC-CHP system and use of -advanced diagnostic, monitoring and controls for fuel cells (SOFC and PEMFC).

Although the research areas are split in terms of application size, it is more interesting to examine the technology progress and state of the art in terms of the two stationary fuel cells technologies (PEMFC and SOFC):

PEMFC technology: Between 2011 and 2021, 14 projects of this pillar are classified as contributing to the development of PEMFC technology. As regards the **CAPEX** target, only one project could achieve the KPI 2020 target for micro-PEMFC using a new generation device. For mid-size PEMFC, three projects readily achieved this target as well as the SRIA State-of-the-Art (SoA) 2020. It gives hope that the 2024 SRIA target can be met by mid-size PEMFC. Additional manufacturing volumes are still necessary to reach this target for micro PEMFC. Concerning the **lifetime** target, up to 20 years of system lifetime and 80,000 hours of stack lifetime are being reported. In general, the research focus seems to be shifting out of PEMFC to SOFC. The main reason for this seems to be the shift of the European industry to SOFC, with PEMFC solutions using technology from abroad (mainly Asia).

SOFC technology: Between 2011 and 2021, 13 projects of this pillar were classified as contributing to the development of SOFC technology. As regards availability, reliability, electrical and thermal efficiency, both device sizes (micro and mid) have met the upper bound of the KPI 2020. Additional work is needed in CAPEX, lifetime, durability of key component (stack) and maintenance cost.

A number of important achievements of Clean Hydrogen JU projects under Pillar 4 can be reported:

- Up to Dec 2021, project **PACE** accomplished excellent results in comparison to SoA; 2,909 units were installed, operating seamlessly for a long time (15 years system lifetime with >50% reduction in stack replacement or no stack replacement during a 10-year service plan). In addition, the manufacturing capacity, for some manufacturers, has been proven to reach 2,300 systems/year per original equipment manufacturer (OEM).
- **OxiGEN** achieved direct current efficiency of 50%, while the target of 30% improvement of electrolyte conductivity was overpassed with an intrinsic conductivity 350% higher than the reference. Also, stack durability of 50,000 hours has been achieved.
- **EMPOWER** contributed to increase visibility and awareness of the potential of renewable methanol. The project achieved the CAPEX MAWP 2024 target: 2,600 €/kWh were achieved⁵⁴ with target being 5,500 €/kWh. Also, stack durability target was achieved.
- **RoRePower** project managed to install 21 off-grid units at sites located in remote areas with harsh climate conditions (from -40 to +50°C), able to give demonstration data. It has achieved several AWP targets, such as: electrical efficiency of > 35% (up to 53% measured in some cases), operation in harsh conditions at -40°C, long-term desulphurisation of 15 month.

GAP ANALYSIS – MAIN JRC RECOMMENDATIONS

PACE project is a big deployment initiative of instalment of nearly 3,000 PEM and SOFC. Cost savings as a result of streamlining the grid connection administration process seems to be missing and should be developed.

The OEM manufacturing capability has been increased with significant innovations in some cases (e.g. reducing the number of components and reducing costs in case of ComSos project). However, a supply chain plan for the OEMs and a hydrogen readiness roadmap for the FC m-CHP industry must be developed.

In the case of Next-generation Solid Oxide Fuel Cell stacks, the co-sintering process of stack (OXIGEN project) must improve. Hot box technology with co-sintered ceramic membrane could be competitive in several years. In addition, the m-CHP may become more relevant and attractive when house owners have to charge their electrical vehicles during the night.

54. An even lower number was reported in TRUST but was declared confidential.

More work to be done on aqueous phase reforming (APR) for methanol fuelled systems as part of two stage reforming process: not high enough catalytic activity in temperature range relevant to project. Exclusion of APR negatively affects the system electrical efficiency.

Finally, the rationale to consider gas turbines fed with low-carbon hydrogen is twofold: i) it can offer a decarbonised solution for the provision of a stable energy supply at the transmission level; and ii) cost wise solution - adaptation of existing gas turbines to hydrogen will reduce the overall costs of the energy transition, as investments in new dedicated assets can be postponed. This would also allow to extend the use of the 180 GW_e gas turbine power generation currently available in Europe. In addition, for the provision of high temperature heat for industry, the use of renewable hydrogen in burners and boilers appears to be better placed than other low carbon and renewable solutions.

5.5. PILLAR 5: CROSS-CUTTING TOPICS

The cross-cutting activity area contains specific supporting activities, structured around three research areas with the following overarching objectives:

Sustainability, LCSA, recycling and eco-design: From a historical perspective, two projects - FC-GUIDE and HyGUIDE (2010-2011) provided a first Life Cycle Assessment (LCA) methodology approach specific for respectively fuel cells and hydrogen technologies. They published reference guidelines going under the common name FC-HyGUIDE. One of the recent projects which used these guidelines was HYTECHCYCLING (2016-2019)⁵⁵, which studied recycling and dismantling strategies applied to the whole fuel cell and hydrogen technology chains.

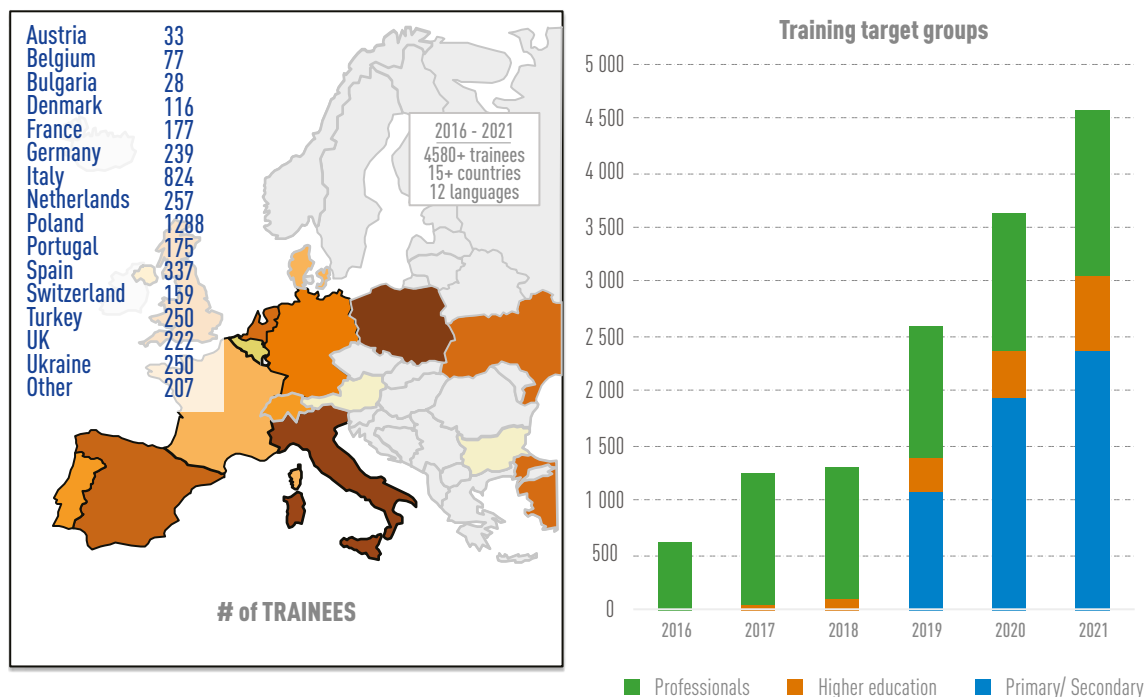
In 2020 these activities were continued by three new projects, SH2E, BEST4HY and EGHOST, which were included in the JRC Programme Technical Assessment. BEST4HY continues the activities of HYTECHCYCLING and is developing recycling technologies for material recovery from two FCH products: PEMFC and SOFC. EGHOST will deliver eco-design guidelines for PEMFC and SOE, and a white book for the eco-design of any FCH product, while SH2E is working on Guidelines for LCSA and Prospective Benchmarking.

Education and public awareness: At the end of the H2020 Framework Programme, this focus area has produced a complete range of tools to train and educate all stakeholders and players along the technology value chain⁵⁶, which is depicted in Figure 24.

55. This project performed a full “cradle to grave” LCA to assess the material flow along the hydrogen supply chain, dedicating particular attention to the critical materials in water electrolyzers (alkaline and PEM) and fuel cells (PEMFC and SOFC).

56. A recent example is project NET-TOOLS (2017-2020), which developed e-learning platform for scientific training purposes, and KNOWHY (2014-2018) which offers trainings for technicians and workers. Part of their achievements have been a useful starting base for TEACHY. Part of the deliverables produced by TEACHY will probably be uploaded on the NET-TOOLS online platform. The project FCHGO is a first of its kind in the frame of the FCH 2 JU, but it finds similarities with the Erasmus+ initiative HYSCHOOLS (2017-20), which developed as well educational and online resources on hydrogen for schools. In addition, HY2GREEN, another Erasmus+ project, had as one of its objectives an innovative training program to develop the technical skills required for a hydrogen ecosystem.

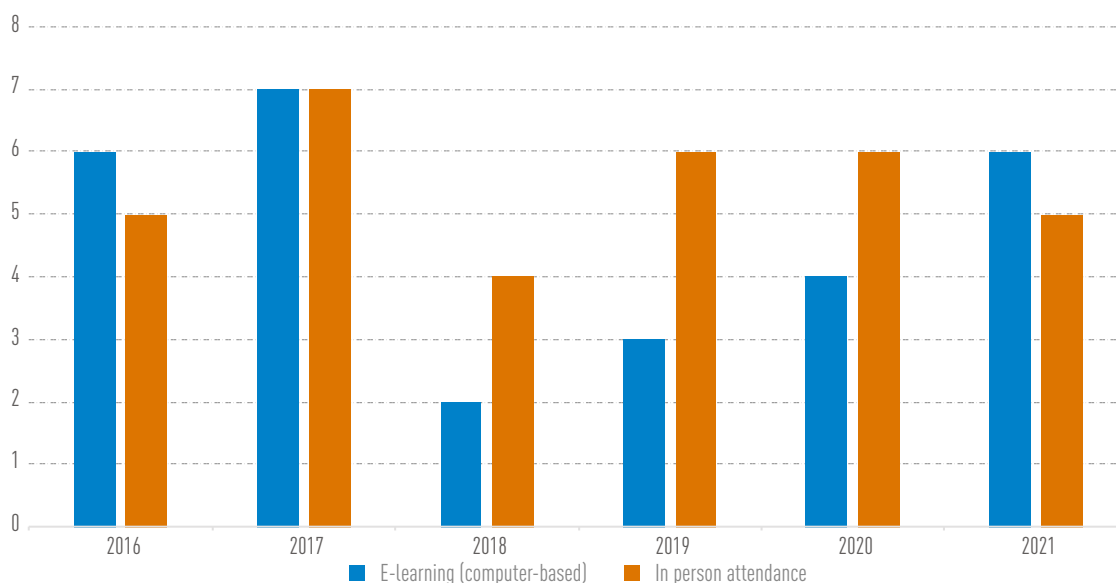
Figure 24: Trainings across Europe and target groups.



Source: EU Hydrogen Research Days including Programme Review, 27-28 October 2022

The COVID-19 crisis and the related lockdown measures in several countries have severely hindered the achievements of the education targets on the individual projects, and this is reflected in overall programme figures for this year, as shown in Figure 25.

Figure 25: Type of training attendance methods per year.



Source: Clean Hydrogen JU

An important role is played by the Fuel Cell and Hydrogen Observatory⁵⁷ (FCHO), which has become a reference provider of structured data and indicators for stakeholders, professional operators and general public. It addresses the past concern related to the lack of long-term availability of training and materials after the completion of the related projects, by providing an updated list of courses and training materials⁵⁸.

Safety, PNR and RCS: A first important step towards proactive safety management were the guidelines provided by the European Hydrogen Safety Panel (EHSP) to this purpose and the related dissemination workshop. Also, the newly introduced safety-related fields in TRUST, such as the hydrogen quantities handled and the availability of expertise, allow a better insight on the ability of the projects, and eventually of the programme, to deal with safety aspects. In particular the information on the number of annual incidents or near-misses will complement the project reporting to the database HELLEN⁵⁹.

In addition to the PNR and standardisation activities, working groups of relevant projects have worked at programme level towards common, harmonised performance tests. These activities propose performance tests, based on the results of PNR projects, which can be used for inter-project comparison and benchmarking of products or technologies and for assessing the technological progress of the programme against quantitative targets.

- **BEST4HY** already delivered some laboratory results: Pt recovery via hydro-metallurgic process, the dismantling of the MEA gaseous phase, and the recovery of Ni-YSZ anode components by Hydrothermal Treatment (HTT) and Hydro Metallurgical Technology (HMT).
- **AD ASTRA** has already achieved a publication record of 20 peer-reviewed articles.
- **THYGA** experts are already contributing to revisions of the existing standards and/or drafting of new standards based on PNR results. The affected standards are part of the European RCS framework covered by the Gas Appliances Regulation 2016/426. For example, one of them is the standard EN 437 Test gases – Test pressures – Appliance categories, which needs substantial modification before being used for certifying gas appliances when working at high hydrogen concentrations.
- A mature LH₂ technology is considered an enabler for the delivery and storage of large quantities of hydrogen. Project **PRESLHY** has set an important step forward in our understanding of the behaviour of released liquid and cryogenic hydrogen, offering a better understanding of liquid and cryogenic spills and their consequences to the environment has generated recommendations for modification of the ISO standard 15916:2015 on Basic considerations for the safety of hydrogen systems (updating work by the WG 29 of the ISO/TC 197).
- The capacity to produce and deliver hydrogen with the required quality for end uses is a critical element for a successful deployment, especially in mobility. Project **HYDRAITE** has progressed towards the quality assurance along the supply chain and facilitated the establishment of three European laboratories able to perform the required analyses.
- In 2021, based on the results of PNR projects, the working group on low temperature electrolyzers has published the report on harmonisation of testing protocols for low temperature electrolysis⁶⁰. In the same year, the working group on high temperature electrolyzers has published an electrolysis vocabulary⁶¹.
- A general frame based on safety principles has been adopted to extract quantitative data and general returns of experience from the database HIAD2.0. The resulting paper has received the “best paper award” by the International Conference on Hydrogen Safety 2021.

57. <https://www.fchobservatory.eu/observatory>

58. For example, by gathering and rationalising results and data of projects, it overcomes their fragmentation caused by their temporary filing on individual websites and platforms.

59. EHSP has also started promoting awareness on this safety aspect by insisting on the necessity of reporting, when reaching out to new projects (for example during the first workshop on project safety plans, May 2022). It has also developed tools and a framework enabling a more coordinated and effective safety management of projects and programme. For example, all new critical projects will be required to provide a safety plan which will be assessed and improves by the EHSP. Moreover, a conceptual frame for extracting a return of experience from incidents is in place.

60. G. Tsotridis, A. Pilenga, *EU harmonised protocols for testing of low temperature water electrolyzers*, EUR 30752 EN, Publications Office of the European Union, Luxembourg, 2021,

61. T. Malkow, A. Pilenga, D. Blagoeva (editors), *EU harmonised terminology for hydrogen generated by electrolysis*, EUR 30324 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-21041-2

Table 2: Standardisation impacts of PNR/RCS/Safety projects.

RCS/PNR project	RCS body/document addressed	Impact on RCS framework
HYDRAITE	ISO 19880-9 - Sampling for fuel quality analysis EN 17124:2018 and ISO 14687:2019	Three certified labs are now able to perform the analyses required by EN 17124:2018 and ISO 14687:2019. Gas sampling techniques protocols at the refuelling station provided to WG 33 for the drafting of the ISO 19880-9. Input delivered also to the Working Group WG 27 (H ₂ quality) and WG 28 (quality control) of the ISO/TC 197, and to ISO/TC 158 on gas analysis
ID-FAST	IEC/TC 105, AHG1, working towards a NWIP for a standard on AST protocols for SOFC and PEMFC	The project has published protocols for PEMFC degradation assessment, which can be used by IEC/TC 105. Two partners are active in the AHG11 and responsible for the integration of project results into an International Electrochemical Commission (IEC) TR document
AD ASTRA	IEC/TC 105, AHG1, working towards a NWIP for a standard on Accelerated Stress Tests (AST) protocols for SOFC and PEMFC	The project has published protocols for SOFC degradation assessment, which can be used by IEC/TC 105. A partner is member of AHG11 and responsible for the integration of project results into an IEC TR document. The expected NWIP was not submitted because the group concluded that it is too early for an international standardisation of testing procedures. The SOFC and Solid Oxide Electrolyser Cell (SOEC) technology still requires widespread acceptance. Nevertheless, AHF11 will further exist, collecting new evidence and paving the way to a future standard
PRHYDE	New ISO 19885-3 Gaseous hydrogen – Fuelling protocols for hydrogen-fuelled vehicles – Part 3: High flow hydrogen fuelling protocols for heavy duty road vehicles	PRHYDE has provided results to ISO/AWI 19885-3, which is under preparation by the ISO/TC 197 WG24
THYGA	Gas Appliances Regulation 2016/426. It refers to several harmonised standards, one of which is EN 437 Test gases – Test pressures – Appliance categories	Assessment of the applicability of the GAR regulation to H2NG blends. Recommendations to modify EN 437 and review of several related harmonised standards mentioned by the Gas Appliances Regulation
PRESHLY	Update of ISO TR 15916:2015 Basic considerations for the safety of hydrogen systems	Project results were used in ISO/TC 197/ WG29 Sub-task 2, in updating the ISO/AWI TR 15916 (the coordinator led this sub-task). The originally foreseen revisions of ISO 13984:1999 and ISO 13985:2006, on LH ₂ land vehicles, were abandoned, because the project results are of a too general character to be used for these very specific standards

RCS/PNR project	RCS body/document addressed	Impact on RCS framework
HYTUNNEL-CS	Recommendations to first responders and standardisation bodies. Local/national rules for parking in garages and accessing tunnels and underpasses.	A recommendations report to standardisation bodies is one of the final deliverables. The most probable recipient will be the CEN/CENELEC JT6/WG 3 (hydrogen safety) for a future standard on built environment safety. Recommendations to all stakeholders for safer use of hydrogen vehicles in underground transportation systems
e-SHYIP	IMO IGF code, guidelines for hydrogen storage on ship.	Results will contribute to the ongoing work at IMO in updating the IGF Code. However, the project does not seem to be able to formally intervene at IMO MEPC level, and this risk to reduce the chance of an impact
MULTHYFUEL	Guidelines for the design and construction of multi-fuels refuelling stations.	The work will facilitate the permitting process for multi-fuels stations. Updating HyLaw, a repository of applicable administrative and legal permitting rules

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Sustainability, LCSA, recycling and eco-design: In line with the required acceleration towards decarbonisation set by policies, Horizon Europe requires sustainability to become one of the principles guiding R&I investment and progress⁶². The preparatory work done by the JU in the years 2018-19 has allowed this stepwise change of focus, materialised in the three new projects dedicated to life cycle sustainability analysis, eco-design and improved recycling techniques.

Also, the SRIA proposes the creation of European Hydrogen Sustainability and Circularity Panel that will guarantee the required coordination between the projects and the programme strategy.

Education and public awareness: Despite the developed tools and methods addressing the needs of a broad range of users, including the first university master (MSc) programme dedicated in its entirety to fuel cells and hydrogen themes, the lack of long-term exploitation, including the failure in keeping updated the materials, is a persisting problem and a matter of concern. Even though the FCHO has gathered all available education tools in one place, this repository is based on links to the original sources, and it is imperative that these links remain active and updated.

In the same context, the Clean Hydrogen efforts need to align with overlapping efforts under programmes with similar scope, like the ERASMUS+⁶³. Finally, the goals of the FCH2 Education platform (a compendium of free-accessed educational resources) might need to be redefined (<https://fch2edu.eu/>).

Considerable resources have been invested by the JU and obtained visible results towards the awareness of stakeholders (policy makers, regulators and permitting authorities)⁶⁴. However, as regards the awareness of

62. All projects will have to embed sustainability and circularity principles in designing their products and their activities. The life cycle analysis must become the reference tool to measure and rank the available technology options.

63. Project FCHgo shows strong similarity with the ERASMUS+ HYSCHOOLS (<https://www.hyschools.com/>). An additional ERASMUS+ project, HYGREEN, has also developed an e-learning platform providing skills to new works forces (<http://www.hy2green.org/>).

64. All projects are now committed to organise a final dissemination event aiming at informing their stakeholders' audience. The annual Programme Review Days and the stakeholders' forums have reached out to increasingly higher policy levels. Also, participation to more general dissemination actions, such as (among many others) the European weeks, scientific and industrial conferences, and to international bodies events such as the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) and the Mission Innovation workshops has strongly contributing to advancements in this area. The Clean Hydrogen JU webpage itself is also part of it, and the FCH Observatory an additional support tool. Project HYLAW should also be mentioned in this context: it has engaged with local and national authorities to identify legal and administrative barriers and to issue recommendations how to improve them.

citizens and local community, the hydrogen community has scarcely engaged with the rapidly growing field on the social dimension of energy ecosystems, including energy diplomacy and energy poverty studies, creating a gap. Project HYACINTH, terminated in 2017, delivered a methodological approach to assist projects in successfully deploying their technology among the public. However, in general, it is not clear how projects have made use of HYACINTH's results by involving the local population and addressing the societal aspects of technological deployment⁶⁵.

Safety, PNR and RCS: On top of the already ongoing effort RCS and the related PNR, further attention has to be dedicated to handling (storage, transport, delivery) of large quantities of hydrogen, both in its compressed and liquid state.

Also, the tools and plans developed by the EHSP have still to be put in practice and improved according to the practical experience. For example, the assessments of the safety planning will very probably need to be enriched, once the first projects have submitted them to the EHSP.

Finally, several projects included in this report have made clear that follow ups are required. This is not due to projects shortcoming, but to the complexity of the topics covered.

5.6. PILLAR 6: HYDROGEN VALLEYS

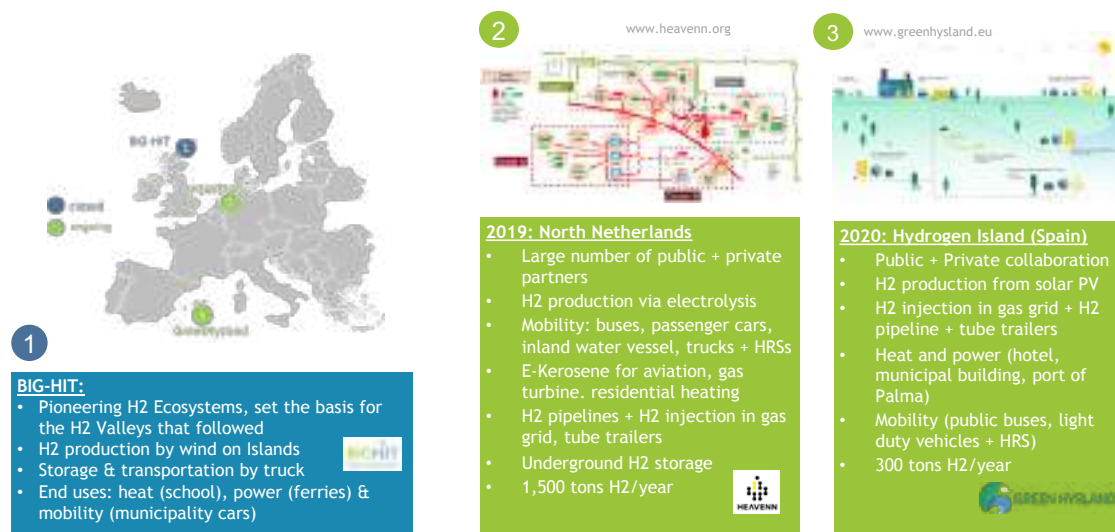
A Hydrogen Valley is a defined geographical area, city, region or industrial area where several hydrogen applications are combined together and integrated within a Hydrogen ecosystem. The idea is to demonstrate how all the different parts of the use of hydrogen as an energy vector fit together in an integrated system approach. This concept has gained momentum and is now one of the main priorities of industry and the EC for scaling-up hydrogen deployments and creating interconnected hydrogen ecosystems across Europe.

As highlighted by the European Hydrogen strategy, Hydrogen Valleys will develop especially around local hydrogen production facilities. Their advantage is seen in sharing of a dedicated hydrogen infrastructure for industrial and transport applications, and electricity balancing, but also for the provision of heat for residential and commercial buildings.

At present, the Clean Hydrogen JU is funding three relevant initiatives, on the Orkney islands (BIG HIT), in the Netherlands (HEAVENN) and on Majorca (GREENHYSLAND), shown in Figure 26. All these projects are centred around the production of hydrogen from renewable sources.

65. There is the brilliant example of project BIG HIT, which successfully engaged with local community in the north of Scotland. It can be assumed that several other demonstration projects, which had to deploy hydrogen systems among the public, have developed and implemented own strategies. There is no trace of this effort and of any structured feedback and lessons learned, which could assist new projects facing the same challenge.

Figure 26: Overview of the three Hydrogen Valleys supported by the clean Hydrogen JU



Source: EU Hydrogen Research Days including Programme Review, 27-28 October 2022

BIG HIT project finished after six years. It has been successful in creating a diverse hydrogen value chain in the Orkney Islands, using curtailed wind power for transport, heating and power applications, and deploying five hydrogen trailers (250 kg hydrogen storage), a hydrogen catalytic boiler (30 kW), 1 MW electrolyser, five hydrogen FC vans and a 75 kW fuel cell system for co-generation. During implementation, there was limited availability of hydrogen due to much less curtailed wind power than expected, and subsequently less hydrogen production. Therefore, the operational phase of the project has been limited. BIG HIT has been very active in maintaining links to other FCH JU projects, like HEAVENN, GREEN HYSLAND and OYSTER. It is also connected to SURF & TURF, HYDIME, PITCHES and HyFLYER, facilitating other hydrogen projects in the area. The project has created the Hydrogen Territories Platform (HTP)⁶⁶, which offers useful tools, such as the replicability tool, and a repository of lessons learned and other relevant information. The HTP has now been taken over by the HEAVENN and GREEN HYSLAND projects.

HEAVENN, located in northern Groningen and Drenthe area, includes the deployment of hydrogen related infrastructure across 4 clusters. In the Chemical Park Delfzijl, the supply of green hydrogen for the production of green methanol (20 MW) and the production of green kerosene at SkyNRG (50-60 MW) is facilitated, including the infrastructure that supplies electricity to electrolyzers. A so-called trailer outlet is also being completed, enabling green hydrogen to be loaded onto trailers and transported to users in the region. Finally, a hydrogen-powered barge is being built, with a hydrogen FC emergency power supply to demonstrate its market application (for a zero emission shore-based power supply).

In Emmen, the gas treatment plant is being converted to produce renewable hydrogen. An at least 4 MW electrolyser is planned to produce green hydrogen which will be transported to the GETEC industry park via a newly constructed pipeline, thus making a significant contribution to the greening of industrial consumption of natural gas. GETEC's gas turbine will be adapted to supply "green" steam to the industry at the park. In addition, an HRS is being built to supply green hydrogen to 10 FCBs (bringing the total number of hydrogen buses in Groningen and Drenthe to 30⁶⁷). Furthermore, the creation of a hydrogen district in Hoogeween is underway. The most prominent projects consist of the development of the first 100 new houses equipped with 100% hydrogen supply are being developed, whereas 250 homes in Erflanden are being converted from using natural gas to hydrogen, with due consideration given to social acceptance of the deployment and use of these systems. Finally, mobility applications appear into the entire region. A vehicle fleet consisting of 105 passenger vehicles, 8 light

66. <http://h2territory.eu/>

67. These FCBs are not supported by HEAVENN.

duty trucks, 8 heavy duty trucks, 4 waste collection trucks, 2 long-distance buses (Qliners) and 2 eight-seater vans will be created. Also, four more hydrogen refuelling stations are being built in Groningen and Delfzijl, among other places, at 350 bar (suitable for heavy transport) and 700 bar (suitable for passenger transport).

GREENHYSLAND will create a 'green hydrogen ecosystem' on Mallorca in the Balearic Islands. Green hydrogen will be used to supply fuel cell buses (to be purchased through additional regional funding) and fuel cell light duty vehicles including dedicated HRS. The hydrogen will also be used to provide heat and power in several buildings, and to supply auxiliary power for port operations. The recently commissioned Hydrogenics 2.5 MW PEM electrolyser will receive electricity from a newly built Photovoltaic (PV) plant (supported with additional national funding). The hydrogen production facility is expected to be operational since the summer of 2022, but the project is facing permitting issues (what has delayed the readiness of the first hydrogen off-takers). In addition, the project plans to inject hydrogen into the gas grid, and there are also plans to construct a new hydrogen pipeline. The additional funding received is a positive sign that there is support for this type of initiative at national and regional level; almost EUR 2.5 million were received for newly built photovoltaic plants and EUR 3.75 million for H₂ buses in the city of Palma. There are also efforts underway to get additional (national) funding for additional H₂ buses and to increase the dispensing pressure of the HRS.

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Mission Innovation 2.0 has the target of 100 Hydrogen Valleys globally by 2030, but simply increasing the number of Valleys should not be the only measure of success. Supporting only mature projects with good prospects for future sustainability, that demonstrate a good example, will be better in the long run.

All Hydrogen Valley projects seem to be developing business cases that could potentially be replicable in other regions. However, by definition, each Valley has different regional traits and the objectives cannot be identical, so every possible business case needs to adapt to the specificities of each case.

Securing the additional funding needed for the full implementation of the Hydrogen Valleys may prove to be a shortcoming, creating delays and increasing uncertainty during implementation. The same applies with permitting. It will be also extremely important to capitalise all the lessons learned and share them with the regions participating in the Project Development Assistance (PDA) support programme of the Clean Hydrogen JU. Coordination between the valleys is already facilitated through the platform, however links to other types of projects should be fostered too, in particular to large scale demonstration projects funded through Horizon Europe.

In terms of planning, future hydrogen valleys should be located near newly built RES, to ensure the availability of green electricity, or in proximity of suitable geological formations for hydrogen storage, if large scale storage is considered as a necessary requirement.

Finally, there are many initiatives that might overlap (the Hydrogen Territories Platform, the Hydrogen Valleys platform and the S3P European platform). One option could be to establish a single consolidated platform, to align and facilitate their activities in common.

5.7. PILLAR 7: SUPPLY CHAIN

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 EC as a strategic value chain for Europe. Considering the expected steep increase of hydrogen demand and production in the next years and towards 2050, a considerable increase in the number of active companies is required along the supply chain. Supply chain includes everything from processing the raw materials into specialised materials (e.g. electro-catalysts), production of components and sub-system to system integration. The supply chain is also complemented by the wider view of the value chain approach vis-à-vis creation of jobs, added value to economy and industry competitiveness.

The JU has conducted a study on the EU supply/value chain for hydrogen and fuel cell technologies, identifying present weaknesses and proposing appropriate solutions.⁶⁸ Additional information on suppliers of FC systems and components, as well as service providers is also to be found in the FCHO. The supply chain of hydrogen-based technologies is still under development and consists mainly of relatively small organisations. About 300 European companies contribute to the development of hydrogen technologies and many more are involved in various steps of the hydrogen supply chain⁶⁹.

The JU has supported a long series of projects on supply chain. From them, there are still three on-going, dedicated to manufacturing. Despite the progress achieved so far, more effort is needed in order to cover a wide range of aspects, ranging from processing of raw materials, to manufacturing of specialised materials, to manufacturing of high quality and low cost components in a large scale, to further recycling and waste management, just to name some of the steps. An important factor is also the training and education of human resources prepared to deal with the problematics of the different supply chain steps.

- **MAMA-MEA** focused on new manufacturing techniques for the catalyst coated membrane (CCM) capable of exceeding the production volume of 1 GW/year, which brings about considerable improvement in materials utilisation and the reduction in use of critical raw materials and scrap, simplifying the manufacturing process, while delivering power density on par with state-of-the-art parts.
- The main European stack manufacturers (Sunfire, Haldor Topsoe, Elcogen and Ceres Power) in the C2Fuel project are currently using the model developed by **LOWCOST-IC**. The project is opening a new way to reduce SOFC cost with a deep investigation on new cheaper materials. Also, the diagnostic tools to investigate material degradation processes developed by LOWCOST-IC project can be implemented in commercial products.
- **INN-BALANCE** managed to develop highly efficient and reliable fuel cell BoP components, reducing the cost of current market products in Fuel Cell System (FCS), and to integrate a stable supply chain for car manufacturing and system integration. The project partners reported during the exploitation workshops that actions will be taken after project end to further develop the INN-BALANCE components to reach other key markets and higher TRL levels to achieve fast commercialisation.
- A new web application developed in the project **INN-BALANCE** by partner Fundación AYESA allowing users to visualise the relative costs of each module and component of the INN-BALANCE automotive fuel cell system and see the benefits of a manufacturing- oriented design approach⁷⁰.

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The Inkjet technology unveiled its benefits and drawbacks as shown in project **MAMA-MEA**. More research is needed to tackle the issues stemming from the chemical incompatibility of the printing heads with the corrosive inks as well as clogging issues and more. The same could apply for BoP optimization and integration of **INN-BALANCE** at further reduced costs.

The Clean Hydrogen JU activities should contribute to reinforce the EU leadership on advanced materials and components used in hydrogen technologies by optimisation of the manufacturing processes, using abundant natural resources, improving the products quality (targeting zero defect products), developing new architecture, reducing the time to market through technological/research platforms, etc. For example, by financing projects contributing to manufacturing of components and their scale-up, following circular approach, including further automation of the manufacturing processes.

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

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

70. The web application is free of charge and can be used by everyone to emphasize the close links between the application and the INN-BALANCE. The application can be accessed by clicking on following link: <https://cost-evaluation.innbalance-fchproject-eu/public/main>.

Besides manufacturing of components, it will also be worth looking at the production of machines/robotics needed for the automation of manufacture processes needs.

Europe should also increase its efforts to develop other cost competitive solutions (e.g. LOHCs, metal hydrides, ammonia, etc.), optimise the roundtrip efficiency of the hydrogenation-dehydrogenation cycle and support their industrial deployment.

5.8. GENERAL JRC RECOMMENDATIONS

In order to further strengthen the Programme Review exercise, it is critical to further improve the data collection process. The EU Survey in particular contained in many cases poor quality of information. Therefore, we see the need to take a number of measures, including the update and simplification of the template, the requirement for the information to be also validated by JU project officers, as in the case of TRUST, but also extend the data collection period to give more time to the projects to properly report them.

Although quality issues are also present in the TRUST submission, which require measures as above, the biggest problem is that about 40% of the data, are reported as confidential. This implies that the current efforts by the JU on the public availability of KPI data are not effective. It is recommended to start a discussion on adopting a Clean Hydrogen JU specific policy on data, which would also address the issue of confidentiality and how to address it to allow proper reporting of the achievements of projects and the progress towards the JU's technology KPIs.

Nominating a data responsible for reporting data from each project could also improve the quality of the data and information given in the EU Survey and TRUST. Guidance on how to report data in TRUST could be provided, for example through an annual webinar. There should be consequences if a project is not reporting, or only partially. It could be discussed whether, as a last resort, payments can be withheld in these cases.

The transition from MAWP to SRIA targets should be further looked into. Although many projects were still funded under the previous framework programme, the programme as a whole should achieve the SRIA targets. Moreover, it is important to check if there are missing KPIs or if any substantial changes are needed for the 2024 targets. The process should begin in early 2023, so that also the 2024 targets can be replaced by the 2024 SoA. In parallel, it is important to automate the collection of the SRIA KPIs, so that they can be tracked more easily and their evolution over time, allowing also the easier monitoring of their progress.

It has been observed that in some projects the step from the laboratory to the demonstration stage is not successful. Two stages projects can be foreseen, a shorter duration project with a lower budget for building the prototype, with focus on materials and components, and if successful, followed by a second stage for operation of the prototype.

Third parties should verify LCAs performed by major JU funded projects. This aspect could be one of the tasks of the sustainability panel. The sustainability panel could also play a role in deciding in which cases verification of the LCAs is warranted, or even play a more direct role in corroborating the outcomes.

In order to improve dissemination of project results, stricter requirements for project web sites should be introduced for new call topics, for example making it mandatory that all public deliverables, papers and presentations are readily available and that websites are regularly updated throughout the life of the project.

06. VIEWS OF THE WIDER SCIENTIFIC COMMUNITY

To achieve the scientific objectives of the Clean Hydrogen Joint Undertaking, all sectors concerned by the hydrogen economy should be given the possibility to get involved in the implementation of its SRIA. Actions undertaken by the Clean Hydrogen JU should take into account not only the views of its public and private members, but also the recommendations of the JRC (as reflected in its Programme Annual Assessment and summarised above), as well as the views of the wider scientific community⁷¹. The views of these actors should input into the activities of the Clean Hydrogen JU (mainly through the Annual Call for Proposals).

6.1. WIDER SCIENTIFIC COMMUNITY (2021) – OPINIONS AND ADVICE ON SRIA

In 2021, during the preparation of the SRIA, the JU made the first attempt to collect the opinions of the wider scientific community via a workshop organised on 30/11/2021 in two sessions, during the second day of the European Hydrogen Week 2021. The JU presented an overview of its planned multi-annual research and innovation (R&I) priorities, covering the whole hydrogen value chain. A particular emphasis was given to the necessary synergies with other end-use partnerships, collaboration with whom will be critical to achieve its goals.

All sectors, including the wider scientific community, were invited to discuss these priorities and ways to bridge the gaps between ready-to-market technology and large-scale uptake, while continuing the efforts to improve and diversify the technological options. A number of relevant points were made during the session discussions, as well as collected through a Q&A application, which are summarised below:

1. There was a general consensus that the partnership approach – including the setting of priorities - followed by its predecessor FCH JU, between the public, private and research sectors, was exemplary. This is proven by the good R&I results of the partnership (and its projects), with the steadily increasing participation of industry and research and the third continuation of FCH JU in its succeeding Clean Hydrogen Partnership.
2. There was also a strong support for the Clean Hydrogen JU to fund activities along the whole hydrogen value chain and across technology readiness levels (TRL). The latter is particularly important, as on one hand early demonstrations are necessary to provide feedback on the developed technologies, while on the other hand low TRL research is essential to provide the next generation of technologies and products.
3. Particular emphasis was given to the need to improve manufacturing capacity and strengthen the capability for mass production, through joint efforts of research with the industry, as this is critical for the envisaged scale up.
4. The activities of the Clean Hydrogen Partnership should also consider the aspect of regional particularities, as optimal production and distribution solutions depend a lot on the local specificities. Here activities such as the hydrogen valleys are considered extremely important (more on the point below).

71. 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.

5. Hydrogen valleys, following an ecosystem approach, should be a priority area. They showcase how the hydrogen economy could work on a local level, but also help identify and resolve issues associated with their operation (and associated business model). Such issues could range from technical ones to purely administrative (e.g. associated with permitting procedures). For a more effective implementation of hydrogen valleys, the idea of creating a sandbox for such projects was proposed. This is in line with the proposal imbedded in the Gas Decarbonisation Package published on 15 December 2021⁷².

In terms of specific scientific priorities, a number of priority areas were proposed by the participants, as follows:

A. HYDROGEN PRODUCTION

A.1 Electrolysis

All electrolysis technologies should be addressed in order to achieve their intended large scale deployment in the short-term, but also to find the winning combination of performance, durability and cost in each case. Focus should also be on the system integration. The three main technologies on the market have not the same level of maturity and face different technological challenges.

Low temperature electrolysis

Alkaline technology is mature and already in a scaling-up phase. It is not suitable for dynamic operation. PEM is more efficient than alkaline and adapted to all types of applications (industry, mobility and grid balancing).

PEM technology is getting mature, but research & innovation is still needed to reduce cost and increase durability (especially for HDV applications). Higher efficiency means an increase in current density from 2.2 SoA up to 3 to 4 A/cm² in 2030 without affecting degradation rate and durability. The reduction of Critical Raw Materials (CRM) / PGM is a priority, and the ultimate goal is to find alternative catalysts.

High temperature electrolysis

SOEL is a less mature technology, it has the great advantage of not using noble catalysts (though some rare earths and Cobalt). It has the best electrical efficiency thanks to its high temperature of operation. This technology is very relevant when heat is available (steam). Thanks to R&D and demo projects (like Multiplhy project, 2.4 MW in a bio-refinery), it is expected that this technology will become competitive with PEM and alkaline.

A.2 Other routes of hydrogen production

Organic wastes and residues, biogas, biomass, are alternatives to produce hydrogen through fermentation or reforming. The cost of these wastes is predictable and make these technologies competitive if the hydrogen produced is consumed on site. The possibility of blending the hydrogen in the natural gas network might be an option. If the hydrogen produced cannot be used on site, then additional transport costs should be considered. These decentralized sources of production are complementary of large scale production through electrolysis.

B. STORAGE AND DISTRIBUTION

To reach the EU target of 40% of RES in the energy mix in 2030, hydrogen will be the only solution to deal with the issue of the intermittent supply of wind and solar-generated electricity. To store large quantity of energy in hydrogen, large scale underground storage will have to be implemented.

72. Commission proposes new EU framework to decarbonise gas markets, promote hydrogen and reduce methane emissions. The Gas markets and Hydrogen regulation and directive show a clear focus on hydrogen. These include (i) as of 2030, a European Hydrogen market fully regulated like the current gas and electricity markets, (ii) with Hydrogen enjoying a “regulatory waiver” in order to support Hydrogen Valley like projects until then.

There are already some examples of such storage in UK (salt cavern in Teesside) and Austria (20% H₂ and 80% of CH₄ in porous rocks). Overall, it is estimated that there are more than 100 underground storage potential sites in Northern Europe, but there is a lack of knowledge on their long term behaviour. A few demonstration projects will be required, in different locations across EU applying different technologies, to highlight the readiness of hydrogen storage for integration within the overall EU energy system.

Regarding the transport and distribution of hydrogen, several pathways must be also considered, such as LH₂ carriers and pipelines.

C. END USES

Research on fuel cells for stationary applications in EU is at a very good level, scaling up will require new manufacturing processes to reduce the costs, especially for CHP in building applications. Electrification of the buildings sector (e.g. via heat pumps) cannot achieve on its own EU's ambitious objectives and need to be complemented by other technologies, most notably hydrogen CHP, therefore research efforts should continue. The next step should be the development of CHP systems running on pure hydrogen.

In transport, due to the wide area of applications, the JU should be more focused, considering also international competition. Transport building blocks should be a priority for the JU, including MEA stacks, their membranes and the application of graphite to improve lifetime components. FCEVs will still play a role, especially in heavy duty transport. Here the JU should focus first on new applications and in parallel on platinum free catalysts solutions research which may take more time to lead to the desired results. Recycling aspects should be considered too. Finally, the use of LH₂ in aviation should be a priority.

D. CROSS-CUTTING ACTIVITIES

Cross-cutting issues are very important and should not be ignored as they support the whole value chain. The partnership should make an important contribution to the development of skills, in particular to attract young researchers.

6.2. WIDER SCIENTIFIC COMMUNITY (2022) – OPINIONS ON WORK PROGRAMME

The Clean Hydrogen JU continued its effort to increase the openness of its Programme, by widening the scope of its Programme Review Days (PRD). In 2022, this part of the Hydrogen Week, traditionally presenting the progress of the Programme and achievements of selected projects, was opened to the wider scientific community for consultation (as required by the SBA – see above too). These days were thus renamed as EU Hydrogen Research Days and included discussion panels for each Pillar with scientists / researchers from the wider scientific community, along with the audience, freely exchanging their views and opinions on the Clean Hydrogen JU Programme, the achievements of its projects and the way forward.

A number of repetitive themes and conclusions (to the precedent year exercise) arose from the different panels during the EU Research Days, which are summarised below:

1. One important conclusion that can be drawn from the JU projects is that most barriers are not so much technological or financial, but arise from the cross-cutting areas of regulation and education. Complex permitting procedures and lack of regulations and standards are observed at national and local level, which are combined with limitations in skilled labour.
2. In parallel, increasing public awareness is critical for the public acceptance of hydrogen technologies. Communication and dissemination of project results and the benefits of hydrogen can help bring these

technologies closer to the public and also allow facilitate the collaboration with regulatory and local authorities. This can then lead to the desired increase of uptake.

3. The availability of resources and components in Europe must be ensured, especially considering the great challenges faced the recent years (during COVID-19 pandemic especially) in terms of supply chain disruptions and lack of materials. Manufacturing capacity in EU must be supported strongly in the coming years, while also working more on materials and related sustainability aspects.
4. Hydrogen Valleys can accelerate technology progress and the uptake of hydrogen technologies, while also facilitate the collaboration between the sector stakeholders (industry, research, SMEs), as they provide an energy ecosystem where all stakeholders can become part of it and see the benefits of hydrogen. They can help to identify regulatory and standards bottlenecks, increase public awareness and provide a “platform” for the collaboration of different stakeholders. If set up appropriately, based on the hydrogen demand needs of the valley participants, then they can ensure hydrogen uptake and address these additional bottlenecks. The Hydrogen Valleys can gradually be replicated or linked among themselves or even with other independent projects, thus further enlarging these ecosystems. In turn they could then provide for the creation of the necessary demand in EU for equipment and components to support in-house manufacturing.
5. Although there is a gradual shift within the hydrogen sector of the focus towards deployment of current technologies, it is important not to stop working on the next generation technologies, for EU to keep its competitive advantage at international level. The research at low TRL should always be in line with the priorities of the industry, so that these technologies can be then exploited and be implemented in the different hydrogen applications. In parallel, research should continuously look into the current technologies and see how it can further improve their performance, while lowering their cost.
6. Synergies will be a key to succeed the above. The national programmes and the Clean Hydrogen JU SRIA should be aligned to avoid unnecessary overlaps but mostly to ensure complementarities and by using the available tools that have been set up, like the ERA Hydrogen Pilot and the SET Plan, to achieve synergies both at the level of research and in deployment. In parallel the Clean Hydrogen JU should collaborate with the end-use related European Partnerships (such as Clean Aviation JU, EU-RAIL JU, Zero waterborne, 2ZERO etc) by discussing with them and identifying the needs of their sectors. Nevertheless, research should not be restricted just to these areas, as hydrogen is an enabler and it is important not to limit it beforehand. In this aspect also collaboration with CETP could be beneficial.

In terms of specific scientific priorities, several priority areas were proposed by the participants (including scientific community), as follows (presented by Pillar):

A. HYDROGEN PRODUCTION

Although the industry technology is maturing with PEM electrolyzers becoming a reliable solution for the production of hydrogen with very low contamination, it is important to continue bringing together large mature industries with small and medium enterprises (SMEs) in projects to deliver the necessary impact and increase the manufacturing scale and technology uptake, including pushing the work on standards and improving the permitting process.

A significant impediment for the projects and the increase of their operational hours, especially for demonstration projects, is the high level of electricity prices, which is the main cost element of hydrogen production. Auxiliary services like electricity grid balancing shall support the financial viability of the hydrogen production installations and the integration of hydrogen technologies in the energy system. On the other hand, the 1-2 €/kg cost of grey hydrogen that used to be the point of reference has moved to 6, 8 or even 10 €/kg following the NG price hikes. To avoid the high cost of electricity and be competitive with grey hydrogen, investors should consider complete renewable hydrogen projects, whereby electrolyzers would use directly renewable electricity from renewable energy technologies that are part of the green hydrogen production investment.

Research & innovation priorities to be considered in next calls:

- A number of challenges still remain to be addressed for the hydrogen production plants: cooling systems, reduction of critical materials, balance of plant, degradation, improved fast response services, heat exchangers, etc;
- To address the cost issue, focus may be given on the connection of electrolysis plants with off-grid renewable energy plants;
- Continued focus on purity for example by incorporating purification units in existing and future production installations;
- Further improvements in the automation of stack production at manufacturing level.

B. HYDROGEN STORAGE AND DISTRIBUTION

Storage in salt caverns and depleted gas fields is at a low TRL, requiring support to continue gaining knowledge and experience especially at large scale, but also to investigate further critical issues (e.g. microbiological aspects for the porous reservoirs).

Regarding research on hydrogen mixtures into the gas grid and separation, RCS and hydrogen strategies are incomplete. Another critical factor is the limited awareness of the impact of hydrogen mixtures in the gas grid from the side of the gas transmission grid operators; one reason for this is their limited collaboration with relevant hydrogen projects (like project HIGGS).

Repurposing of gas pipelines and blending are both considered in the Programme, but the focus should be in repurposing as the more permanent long-term solution. In the short to medium term, the choice between the two is more dependent on what options are actually available to serve the customer needs. In refuelling, many synergies can be achieved with hydrogen valleys, heavy duty transportation and other end-uses.

Research & innovation priorities to be considered in next calls:

- Hydrogen Storage in salt caverns and evaluating the storage potential in porous reservoirs;
- For LOHCs low PGM catalysts for dehydrogenation are expected to be a critical element to reduce/eliminate the use of critical materials;
- For LOHCs reducing the required energy to hydrogenate and dehydrogenate;
- Significant work needed to improve the RCS framework; collaboration with regulatory authorities is advisable.

C. HYDROGEN END-USES: TRANSPORT

Overall, it was agreed that the Programme is well structured and covers all transport areas sufficiently.

C.1 Building Blocks

The funded projects show that the developments in the building blocks for transport applications (fuel cell systems and on-board storage) is progressing smoothly. Building blocks are an essential area of research and will continuously require to invest in it to improve different aspects, like in components, materials and performance. More importantly though it is recommended that they are developed for all (if possible) transport applications, and then only to be customised accordingly to each specific application, as the optimal approach will differ in each case (e.g. different performances required by aviation compared to other modes of transportation).

Many new material developments warrant further research on this area. Moreover, there is already competition in materials, especially carbon fibres for tanks/on-board storage. This is expected to become further intense moving to mass-production. So it is critical to further work on materials and their sustainability aspects. Recycling should also be considered, as it has the potential to reduce costs.

Research & innovation priorities to be considered for next calls:

- Further research on materials as a priority, as for example components must be made more compact and lighter;
- More work is required to improve building blocks in terms of power density, durability, fuel efficiency. To progress more efficiently though it is important that all related components and aspects are developed in parallel, altogether;
- As degradation is better understood, more focus should also be placed on mitigation strategies to reduce it;
- High temperature applications should be considered more in the Programme;
- The work on building blocks should not exclude cars and buses; these will always need to be supported if we want to remain competitive and not fall behind international developments;
- Modelling should be used in combination with empirical methods to analyse project results.

C.2 Transport Applications

So far the different transport modes were addressed separately. This should gradually change, in combination with the research on the building blocks, so that a more integrated view on how to move ahead on hydrogen in mobility can be developed.

FCEV car and FCB demos have demonstrated that they are a competitive solution. It is important now to invest more in fleets to scale up and reduce costs. In parallel it is important to invest in supply chains, so that mass-production can be enabled and the FC can be built in EU, especially considering the low TRL of European FC suppliers and the supply chain issues that are observed the recent years. This is probably where EU lacks the most compared to its global competitors, not in technology readiness.

Another solution is to invest in hydrogen ecosystems, ranging from the vertical integration of the transport supply chain to setting up hydrogen valleys like ports, enabling the technology to be further developed and integrated in the economic sectors.

Two main problems identified in most demonstration projects were the low availability of HRS and the lack of regulations. Therefore, more attention is required on these aspects.

Research & innovation priorities to be considered in next calls:

- EU needs to put in place its own supply chains for the mass production of fuel cells for transport applications (and not only);
- For demonstration projects data monitoring remains a challenge to be addressed.

D. HYDROGEN END-USES: CLEAN HEAT AND POWER

Significant technological progress has been achieved over the past 15 years as shown by the projects, from the initial few hundred hours of operation achieved in the first projects to the several thousands of operational hours, with high efficiency and low degradation in the most recent ones.

From a technology point of view, it is important now to work on the development of different performance aspects to cover the diverse needs of end users. The requirements to cover these complex operations require more developments, in particular in relation to the flexibility of the systems and their adaptability to different clean fuels (hydrogen, ammonia, renewable gases).

The main challenges now are less technological, as the maturity has increased, but more related to the business models, especially when consumers are gradually transformed to prosumers. The biggest problem is finding on one hand hydrogen to operate the systems and on the other hand, customers willing to invest in such applications.

It is important to look at collaboration with other sectors, e.g. in the context of hydrogen valleys. Moreover, the regulatory framework needs to evolve.

Research & innovation priorities to be considered in next calls:

- FC technology must become more adaptable and flexible to end-use, while allowing the input of a wider range of clean fuels;
- Further research is required on materials to increase lifetime of stacks, reversibility, as well as improving degradation, modularity, stability of the system;
- Develop and automate processes for mass manufacturing of FC systems to reduce costs of components;
- It is important to address the aspects of openness and make results from projects accessible to the public and especially to the research community and the industry.

E. CROSS-CUTTING TOPICS (FOCUS: PNR)

Synergies and even the inclusion of European/national (and regional) standardisation bodies/technical committees in projects could facilitate the exchange of information and the uptake of project results in the updates of standards. Clean Hydrogen JU can further contribute to standardisation through its PNR activities.

Regulators are sometimes not aware of the existence of relevant standards, which should be addressed by future projects aiming at increasing their awareness and capacity building.

Contribution of JU in the mapping and awareness of the specific standards missing to the relevant authorities might identify gaps and accelerate adoption of the necessary legislative measures. Also, preserve the knowledge and maintain a repository to support the projects as well, in addition to its support on pre-normative research.

Research & innovation priorities to be considered in next calls:

- It is necessary for pre-normative research to address the gaps with existing standards. In terms of storage and distribution, large scale hydrogen storage needs to be studied and analysed further, but also LH₂, LHOC, metering of hydrogen, quality control. In mobility, focus should fall more on homologation of new vehicle and vessel types, refuelling protocols, etc.;
- Increase the awareness and support the capacity building of regulators and local authorities in terms of RCS;
- Experience from demonstration projects should be shared / collected to further support RCS development.

F. HYDROGEN VALLEYS

The participants agreed that although funding is important, it is not the main issue for (at least these) hydrogen projects. More important is identifying the consumers of the hydrogen, and specifically the ones that are ready and able to consume it.

Dissemination of valley's experiences (both at European and International level) is critical. All valleys 'learn by doing'; thus, it is important to share this knowledge quickly and effectively to facilitate leapfrogging. H2V platform under the Mission Innovation can support this transfer of know-how, including at international level.

Permitting issues are faced by all projects, mainly due to limited awareness of local administration. Also, co-operation with national authorities like NOW⁷³ could be a topic to continue working on.

73. <https://www.now-gmbh.de/en/>

There should not be a single approach to support valleys. Large-scale and small-scale types are both relevant, it all depends on the local context and the actual needs for hydrogen. Small valleys are important, in particular for replication and further expansion.

Funding support to CAPEX is needed (like in the valleys topics/grants), but it is not the only useful instrument to accelerate Hydrogen Valley deployment. Current JU support to PDA is a useful instrument aiming to initiate a pipeline of projects. Moreover, funding synergies among EU and national programmes do not always work. There is a need to work at both European and national level to streamline complementarities of funding programmes.

Research & innovation priorities to be considered for next calls:

- Already from existing projects salty marine environments have proven to have their unique challenges; worth to further fund similar projects and identify best solutions;
- Hydrogen Valleys can benefit from projects like HyLaw, which can facilitate the collaboration with the local authorities. Moreover, transferring the know-how from other valleys, e.g. via JU projects or the H2V platform, can help create faster the necessary understanding and raise public awareness in relation to hydrogen and the hydrogen valleys.

G. SUPPLY CHAIN

Projects have shown promising results as regards the technologies to enable massive production of the necessary components to scale-up supply of FC. However, high volume demand that will allow these technologies to be further applied in continuously working production lines is still missing. Mass production would require also progress on other relevant aspects, like quality control, recycling etc.

Volume commitment in every single part of the supply chain will be decisive to develop EU's manufacturing capacity. European manufacturers need to be supported; the mistakes of the past should not be repeated, e.g. with PV manufacturing.

Standardisation of FC types and features/sizes and wider use of the same types depending on the application could reduce drastically the deviation and complexity in terms of supply chain response, quality control and standardisation maintenance in the large scale.

Research & innovation priorities to be considered in next calls:

- Focus should be in automation and quality control when manufacturing large volumes of products.

07. STUDIES ON HYDROGEN

In this section the JRC assessment and recommendations, as well as the views of the wider scientific community and stakeholders, are complemented by interesting results of studies procured by the JU or selected studies published by international organisations following the developments in the hydrogen sector in 2022.

In June 2022, the Fuel Cell and Hydrogen Observatory⁷⁴ published its annual set of reports summarising the developments over the past year in the areas of hydrogen technology and market, supply and demand, policy, standards, patents, education and training. Some interesting findings include the increase of fuel cell system shipments by 75.7% in 2021, the operation of 170 HRS and the registration of 3,885 new FCEVs by the end 2021, as well the commissioning of 14 new electrolyser units in Europe, with a total capacity of 27 MW. Supply and demand remained relevantly stable, while 11 new standards were published.

In September 2022, the Clean Hydrogen JU published a study on the impact of deployment of infrastructure for BEV and FCEV⁷⁵. The aim of the study was to examine the optimal mix of BEV charging vs FCEV refuelling stations, as well their optimal size, capacity and location. Based on a range of possible futures and sensitivities, the study concludes that to decarbonise the EU Road fleet, both BEV and FCEV infrastructures will be needed and eventually will cost less than going in a single direction (any of the two). Therefore, it is necessary not only to continue research on the HRS infrastructure, but also to examine the possibilities for synergies with BEV infrastructure, as both are key technologies for clean renewable energy-based transport.

An updated report on Hydrogen Valleys was also published⁷⁶ in September 2022. The report summarizes the emerging hydrogen market today and presents insights on Hydrogen Valleys from around the world. Hydrogen Valleys already play an integral part in building further momentum in the global hydrogen market, while also providing the paradigm for producing, importing, transporting and using clean hydrogen (Figure 27). The report presents the main Hydrogen Valleys archetypes that have emerged and then proceeds to provide examples of Hydrogen Valleys from around the world.

74. <https://www.fchobservatory.eu/index.php/reports>

75. https://www.clean-hydrogen.europa.eu/media/publications/study-impact-deployment-battery-electric-vehicles-bev-and-fuel-cells-electric-vehicles-fcev_en

76. https://www.clean-hydrogen.europa.eu/media/publications/update-report-hydrogen-valleys-and-mission-innovation-hydrogen-valley-platform-was-published-22_en

Figure 27: Hydrogen Valleys Ambition



Source: Clean Hydrogen JU, Roland Berger

In October 2022 JRC published a technical report on the Assessment of Hydrogen Delivery Options, examining the feasibility of transport of green hydrogen within Europe.⁷⁷ JRC has performed a comprehensive study regarding the transport of hydrogen to investigate which renewable hydrogen delivery pathways are favourable in terms of energy demand and costs. The study reveals that there is no single optimal hydrogen delivery solution across every transport scenario. The most cost-effective way to deliver renewable hydrogen depends on distance, amount, final use, and whether there is infrastructure already available. For distances compatible with the European territory, compressed and liquefied hydrogen solutions, and especially compressed hydrogen pipelines, offer lower costs than chemical carriers do. The repurposing of existing natural gas pipelines for hydrogen use is expected to significantly lower the delivery cost, making the pipeline option even more competitive in the future. By contrast, chemical carriers become more competitive the longer the delivery distance and open up import options from suppliers located, for example, in Chile or Australia.

On the international stage, International Energy Agency (IEA) published its annual Global Hydrogen Review 2022⁷⁸ tracking international developments in hydrogen production and demand, as well as progress in critical areas such as infrastructure development, trade, policy, regulation, investments and innovation. This year's report included a special focus on how the global energy crisis sparked by Russia's invasion of Ukraine, which has accelerated the momentum behind hydrogen and on the opportunities that it offers to simultaneously contribute to decarbonisation targets and enhance energy security.

The report notes that although several key technologies are ready to scale up and accelerate development, a number of them are still at early stages of development. Therefore research, innovation and development are critical to demonstrate the viability of these technologies and to support continued cost reduction of technologies that are nearing commercialisation. Moreover, the report identifies certain technology areas where further research is needed, most falling under Pillar 2 of the Clean Hydrogen JU Programme:

- In offshore pipelines, especially in terms of repurposing natural gas networks to hydrogen, where significant reconfiguration and adaptation will be needed;
- In extending the blending limit for the integration of hydrogen to the natural gas transmission networks above 20%, which seems to be its technical upper limit above which significant investment may be needed for certain types of applications;

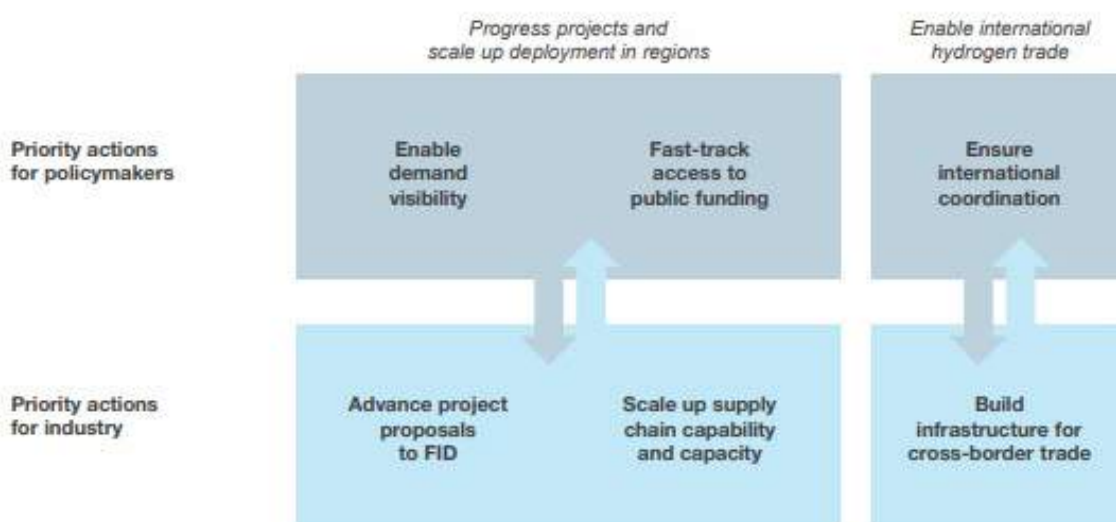
77. Ortiz Cebolla, R., Dolci, F. and Weidner, E., *Assessment of Hydrogen Delivery Options*, Publications Office of the European Union, Luxembourg, 2022, doi:10.2760/869085, JRC130442.

78. <https://www.iea.org/reports/global-hydrogen-review-2022>

- In many areas related to the salt caverns, including the assessment of the integrity of the salt cavern when subject to fast cycling and the required research development and demonstration for storage in porous reservoirs⁷⁹;
- In building evidence and reduce uncertainty about the risks of hydrogen leakage across the value chain, and especially to assess how leakage levels might change with repurposed natural gas infrastructure, as well as for new hydrogen infrastructure and operations that will be developed to support the international trade of hydrogen;
- On the support of research to get more clarity on the global warming potential effects of hydrogen, which remain uncertain, including by developing climate models that take into account the characteristics of hydrogen leakage⁸⁰.

Focusing more on deployment, Hydrogen Council released its H₂ Insights 2022 report⁸¹, providing an updated perspective on global hydrogen market developments and the actions required to unlock hydrogen at scale. According to it, there is a pipeline of hydrogen projects that is growing continuously, identifying 680 large-scale projects worth USD 340 billion, but actual deployment is lagging behind. Europe leads on proposed investments, but China is the one leading on actual deployment of electrolyzers and Japan and South Korea in fuel cells. The report then proposes a series of priority actions for both policymakers and industry to overcome the challenges and accelerate large-scale hydrogen deployment (Figure 28).

Figure 28: Policy and Industry Priorities for 2022-2023.



Source: Hydrogen Council

Hydrogen Council also authored with McKinsey another report, the Global Hydrogen⁸² Flows, addressing the midstream challenge of aligning and optimizing global supply and demand. The aim is to provide a perspective on how the global trade of hydrogen and derivatives, can develop as well as the investments needed to unlock the full potential of global hydrogen and derivatives trade. The report finds that trade can lower the cost of hydrogen

79. According to the IEA report progress remains slow. More research is needed to evaluate the effects of residual natural gas in depleted fields, in-situ bacteria reactions in aquifers and depleted gas fields that may yield contaminants and hydrogen losses, and storage tightness that may be compromised by the characteristics of hydrogen. The Clean Hydrogen JU projects *Hystories* and *HyUSPR* address some of these issues.

80. See also the JRC technical report [JRC130362](#), summarising the conclusions from a jointly organised workshop by the Clean Hydrogen JU and the US Department of Energy on the impacts of "Hydrogen emissions from a hydrogen economy and their potential global warming impact".

81. <https://hydrogencouncil.com/wp-content/uploads/2022/09/Hydrogen-Insights-2022-2.pdf>

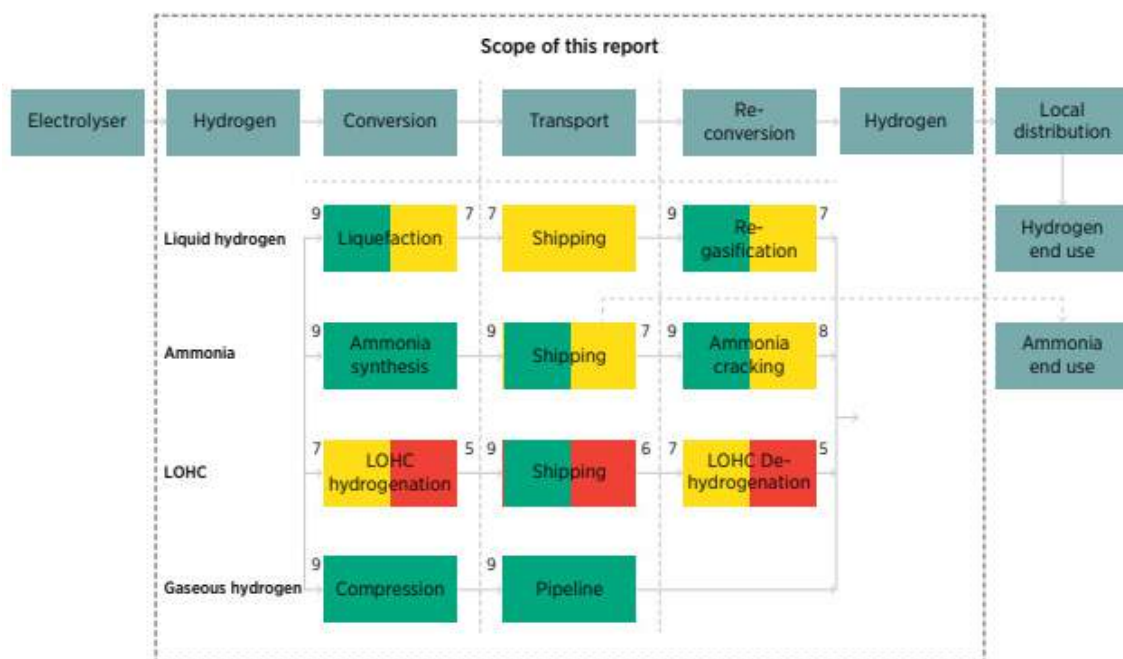
82. <https://hydrogencouncil.com/en/global-hydrogen-flows/>

supply by 25%, with about 60% of the trade performed over long-distances. Overall, around 50% will be performed using pipelines, while another 45% transported on ships (mostly hydrogen derivatives), with Europe relying on imports.

In 2022, International Renewable Energy Agency (IRENA) released three reports on Global H₂ Trade by 2050⁸³, covering first the trade outlook, then reviewing the technologies associated with hydrogen carriers and then closing with the green hydrogen cost and potential. IRENA finds that with a 1.5°C future scenario around 25% of hydrogen could be globally traded - half in the form of ammonia transported by sea, and half through gaseous hydrogen pipelines concentrated in Europe and Latin America.

An important conclusion is that the critical factor that will determine the cost-effectiveness of trade in hydrogen will be whether scale, technologies and other efficiencies can offset the cost of transporting the hydrogen from low-cost production areas to high-demand areas. An important barrier to trade is that many technology options are not commercially available today, thus potentially leading to longer lead times to achieve the large scales necessary, until the technology moves from research to demonstrations to commercialisation (Figure 29). Moreover, the role of trade depends on the conversion costs and efficiencies that will be achieved in the future. Strategies like reduction of material use, substitution and recycling still need further research and implementation.

Figure 29: Processing steps of the hydrogen value chain for each of the hydrogen transport options⁸⁴



Source: IRENA

83. <https://www.irena.org/publications/2022/Jul/Global-Hydrogen-Trade-Outlook>

84. Colour code is a traffic light convention for technology maturity based on TRL: Green = TRL 9; yellow = TRL 7-8; red = TRL 6 or less. For more information see the IRENA report (Part II, page 21).

08. BARRIERS TO ENTRY IN HYDROGEN MARKETS

The Clean Hydrogen JU has been tasked in its founding Regulation⁸⁵ to assess and monitor technological, economic and societal barriers to market entry, including in emerging hydrogen markets. This is per se a difficult task, considering that hydrogen is both an energy carrier with multiple applications and production methods, as well as a feedstock. Moreover, with mature hydrogen applications only now entering the market, many of these barriers become known only now.

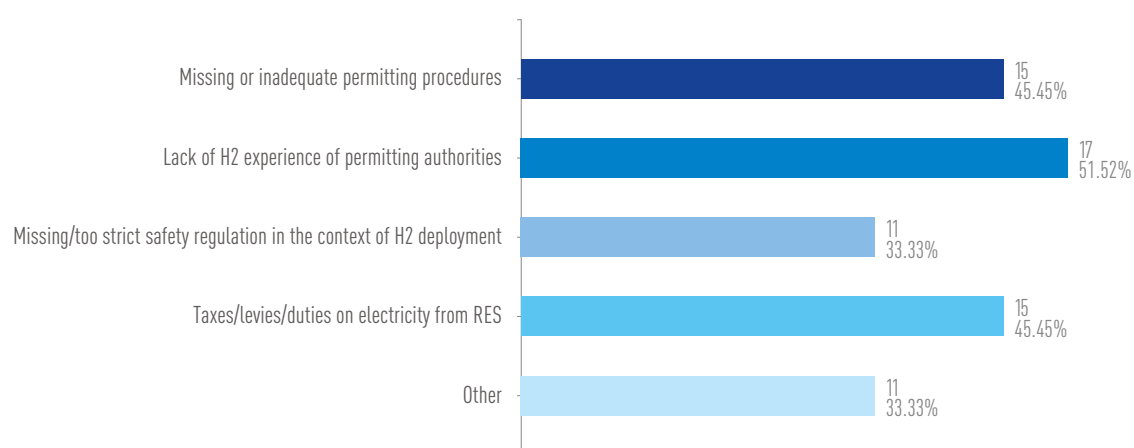
In order to identify such barriers, one should look on large-scale hydrogen flagship projects, addressing production and consumption in multiple sectors of the economy. Hydrogen Valleys thus constitute an ideal source for such information. The Hydrogen Valleys platform collects such information, separating the barriers in three different categories⁸⁶. The results from the surveys so far⁸⁷ are presented below, per category.

8.1. MAIN BARRIERS - REGULATION

This question provides insights into the main regulatory hurdles of Hydrogen Valleys displaying both the number of Valleys as well as the share of all Valleys⁸⁸ that identified the respective hurdle. Please note that the Hydrogen Valleys were able to choose multiple answers.

Comparing the replies at global level and in Europe, one sees that the lack of hydrogen experience of permitting authorities and the missing procedure have roughly the same share, close to 45% and 50% in the two cases. Differences appear in the existence of missing or strict regulations and the tax levies on electricity from RES, which appear as a bigger barrier in Europe.

Figure 30: Figure 30. Main Regulatory Barriers - Global



Source: Hydrogen Valley Platform

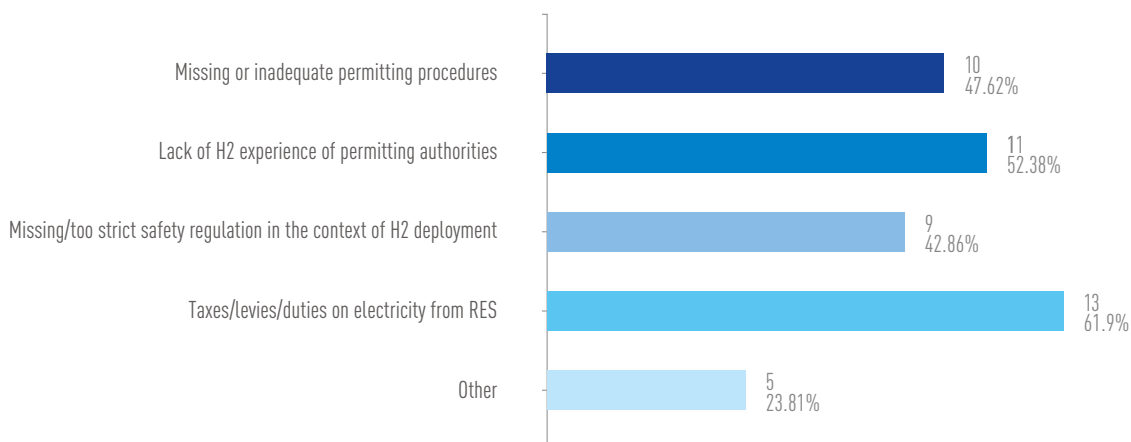
85. SBA Article 74 (a)

86. <https://h2v.eu/analysis/barriers/regulation>

87. Concerning 38 Valleys at the time of the drafting of the text.

88. 38 Valleys in total, 13 of which outside Europe.

Figure 31: Main Regulatory Barriers - Europe



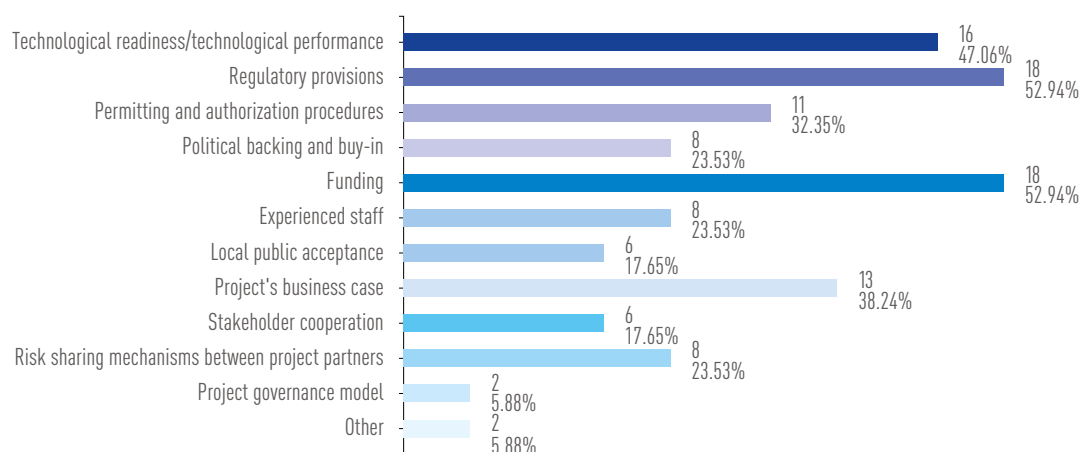
Source: Hydrogen Valley Platform

8.2. MAIN BARRIERS – PROJECT DEVELOPMENT - PREPARATION

This question provides insights into the main hurdles and barriers for Hydrogen Valleys in the preparation phase displaying both the number of Valleys as well as the share of all Valleys that identified the respective hurdle. Please note that the Hydrogen Valleys were able to choose multiple answers.

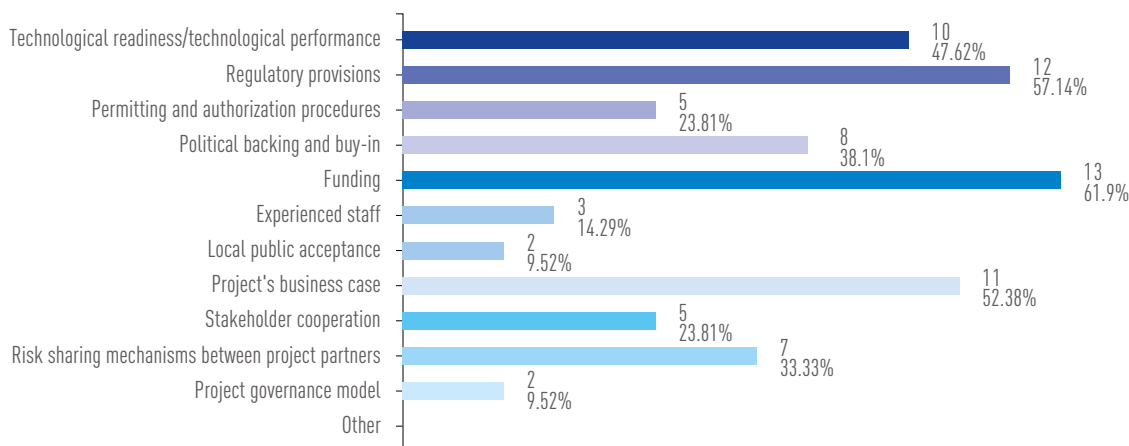
Comparing the replies at global level and in Europe, one sees that financial aspects like the funding and the project's business case are bigger barriers in Europe, while permitting and finding experienced staff constitute bigger barriers on a global level. Political backing is a bigger barrier in Europe, contrary to local public acceptance which is a bigger barrier on a global level.

Figure 32: Main Project Preparation Barriers - Global



Source: Hydrogen Valley Platform

Figure 33: Main Project Preparation Barriers - Europe



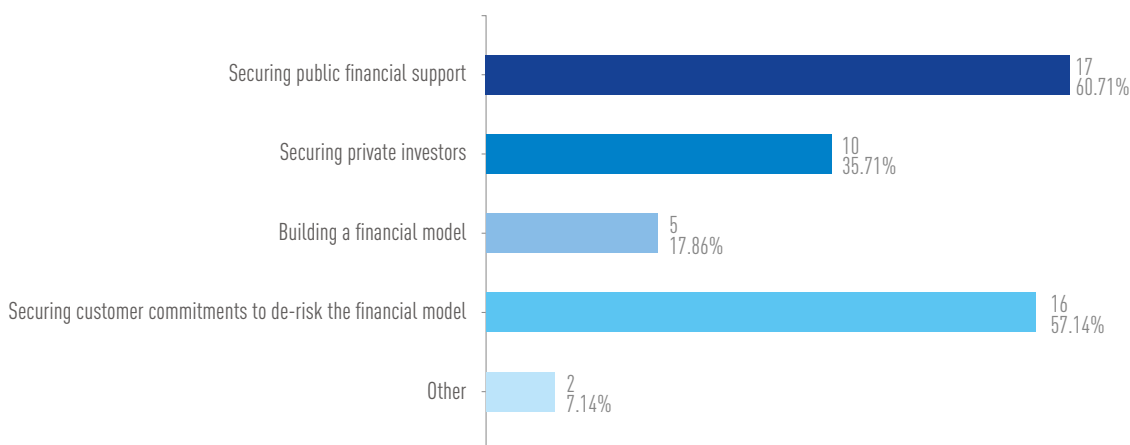
Source: Hydrogen Valley Platform

8.3. MAIN BARRIERS – PROJECT DEVELOPMENT - FINANCING

This question provides insights into the main hurdles and barriers for Hydrogen Valleys in the commercial and financing phase displaying both the number of Valleys as well as the share of all Valleys that identified the respective hurdle. Please note that the Hydrogen Valleys were able to choose multiple answers.

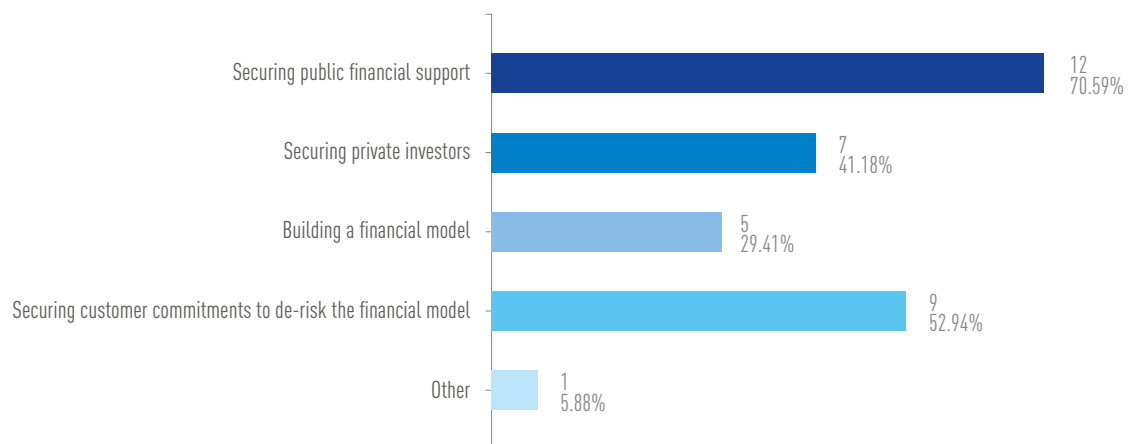
The answers to the questionnaire support the findings in the preparation questionnaire, that the funding part is seen as a bigger barrier in Europe than globally. Nevertheless, in both cases securing the public financial support and customer commitments to de-risk the financial model are the two main barriers.

Figure 34: Main Project Financing Barriers - Global



Source: Hydrogen Valley Platform

Figure 35: Main Project Financing Barriers - Europe



Source: Hydrogen Valley Platform

09. PROGRESS TOWARDS JU's STRATEGIC OBJECTIVES

The Clean Hydrogen JU has been set up to achieve a number of objectives described in the EU legislation and its related SRIA:

- The objectives of the Horizon Europe Programme, as described in Article 3 of the Horizon Europe Regulation, including contributing to the Union policy objectives;
- The objectives set out in the SBA establishing the Clean Hydrogen JU, both common for all Joint Undertakings and the specific ones for the Clean Hydrogen JU, as described in Articles 3 to 5 and 73-74 of the SBA;
- The research objectives set out in the SRIA per research area.

The Clean Hydrogen JU has established a monitoring framework to track the progress towards its objectives as set out in the SBA and the Horizon Europe Regulation, as well as its contribution towards the priorities of the Union and the SRIA⁸⁹, based on a number of KPIs described in Section 7 of its SRIA. These indicators can be grouped in the following categories:

- a) Horizon Europe KPIs,⁹⁰ defined in the Horizon Europe Regulation as Key Impact Pathways and applicable for the whole Horizon Europe Programme;
- b) Common JU Indicators, as defined in the monitoring framework⁹¹ developed by the Expert Group set up to support the strategic coordination process of the European R&I partnerships;
- c) Clean Hydrogen JU KPIs, defined by the Clean Hydrogen JU⁹² for the purpose of monitoring the progress towards the objectives of the Strategy Map and its relevant targets;
- d) Technology KPIs, defined by the Clean Hydrogen JU⁹³ to monitor technology progress and innovation of its projects towards the R&I priorities defined in the SRIA.

The Horizon Europe KPIs are tracked to a large extent by the European Commission tools (CORDA and Horizon Dashboard) and are only reported in the Annual Activity Report of the Clean Hydrogen JU. The Common JU Indicators are prepared and analysed by the Expert Group and reported in the Biennial Monitoring Report on European Partnerships⁹⁴. The performance against the Technology KPIs is analysed in JRC's Programme Technical Assessment report.

This section analyses the third category of these KPIs, the ones specific for the Clean Hydrogen JU, reporting the progress of the JU towards its objectives reflected in its Strategy Map based on the latest available data. For the first year of reporting this set of KPIs, very limited results are available as no project has started yet from the

89. Articles 5.2(h), 17.2(a), 19.4(f)/(g)/(o), 36, 74(a) and 171 of the SBA.

90. HE Regulation Art 50(1) & SBA Art 171(2)(a-c-d-e)

91. A robust and harmonised framework for reporting and monitoring European Partnerships in Horizon Europe, 2021, RTD, <https://europa.eu/!b3TBfW>.

92. Annex I of the SRIA

93. Annexes II-VI of the SRIA.

94. [Performance of the European Partnerships](#): Biennial Monitoring Report (BMR) 2022 on partnerships under Horizon Europe, May 2022 (also translated [factsheets](#) and the [interactive report](#))

new budget/appropriations. Therefore, the focus will be more on the presentation of the KPIs and their baseline values.

The JU specific KPIs are split into three layers, each measuring the progress towards the related objectives of the JU, as defined in the SBA:

- The KPIs on resources, processes and activities monitor the actions and activities of the JU are in line with the operational objectives and tasks of the JU and fall in line with the activities described in Clean Hydrogen JU's SRIA.
- Similarly, the KPIs on outcomes monitor the progress towards the specific level objectives of the JU, which identify what should be the main direct outcomes and results from the activities of the JU. At the same time these should be contributing to the general level impacts of the JU. Therefore, this KPI level also provides a link between the operational level resources and actions to the desired general level impacts of the EU policies.
- Finally, the KPIs on impacts monitor the progress towards its general level objectives of the JU, which are associated with its contribution towards the achievement of macro level objectives of the EU and in particular the Green Deal and the Hydrogen Strategy.

The methodology followed for measuring the KPIs is reported in ANNEX 1.

9.1. RESOURCES (INPUT), PROCESSES AND ACTIVITIES

This set of indicators monitors the actions of the JU that will lead to the desired outcomes and impacts. The activities that can contribute towards this are on one hand the JU's Calls for Proposals and on the other hand its supporting activities, as described in detail in the SRIA and AWP. The indicators, the associated strategic objectives, their baseline and targets are reported in Table 3 below.

The first four indicators monitor the percentage of the budget or the number of projects associated with the three strategic objectives at operation level of the JU. KPI-1 is split into two sub-indicators⁹⁵ to better capture two different approaches towards the definition of sustainable solutions.

The two subsequent indicators are qualitative indicators. KPI-5 mainly draws upon the activities of the knowledge management contributing towards this area, most notably the Programme Review exercise, contributing towards the task foreseen in Article 74 (a) of the SBA. KPI-6 draws upon a number of activities of the JU related to market uptake, focusing on the ones in relation to (a) JU's contribution to the development of regulations and standards, as foreseen in Article 74 (b) of the SBA, and (b) supporting the European Commission in its international initiatives on the hydrogen strategy, as foreseen in Article 74 (c) of the SBA.

95. Note that certain projects may fall both under KPI-1a and KPI-1b, but double counting will be avoided as in the sum of the two indicators such projects will be counted only once. This is the reason that the sums of targets of 2025 and 2027 for KPI-1a and KPI-1b does not sum to KPI-1.

Table 3: Clean Hydrogen JU KPIs, monitoring the progress towards the operational objectives of its Strategy Map

Strategy Map Objective	KPI Name	Unit of measurement	Baseline	Target 2023	Target 2025	Target 2027	Ambition >2027
Resources (input), processes and activities							
Supporting sustainable solutions	1. Supporting sustainable solutions (total)	% of budget	2.5	20	35	50	
	1a. Hydrogen end-use solutions in hard to abate sectors	% of budget	2.5	15	30	40	
	1b. Circular and sustainable solutions	% of budget	<1	5	10	15	
R&I for hydrogen technologies	2. Early research projects	% of budget	10	10	10	10	
	3. Demonstration projects	# of projects	43	20	40	60	
Supporting market uptake of clean hydrogen applications	4. Education and training	# of projects	4	2	4	6	
	5. Monitoring technology progress	Qualitative indicator	N/A	N/A	N/A	N/A	
	6. Supporting EC in H2 market uptake	Qualitative indicator	N/A	N/A	N/A	N/A	

9.2. OUTCOMES

The KPIs on outcomes monitor the main direct outcomes and results from the activities of the JU, which should be contributing to its general level impacts. The outcomes should be in line with the specific objectives of the JU, as defined in the SBA. They both focus on the acceleration of the transition towards the goals set by the Green Deal, the enhancement of the research and innovation ecosystem, including SMEs and involving stakeholders in all Member States, as well as the delivery of innovative technology solutions and their uptake by the market, with the view to local, regional and Union-wide deployment. They are measures through the results and activities of the JU and the projects it funds. The indicators, the associated strategic objectives, their baseline and targets are reported in Table 4 below.

Four out of the eight KPIs (counting separately the two sub-KPIs of KPI-8) are based on the results of Clean Hydrogen JU projects will deliver. For these indicators, the 2023 Target that was set in the SRIA has been complemented below by “Not Applicable?”. The reason is that the first projects of the JU will only be signed in the end of 2022, therefore it is not expected that the projects will be able to deliver results already from 2023.

The first three KPIs in the table aim to capture two sought-after aspects of the JU projects: sustainability and cost reduction. Considering though on one hand the different ways to capture sustainability aspects, and on the other hand the multiple electrolyser technologies and transport applications with different associated costs, the determination of these two KPIs is not straightforward and will be determined with the assistance of experts.

On the contrary, KPI-11 and KPI-12 are more straightforward in terms of definition. Note that as an exception to the other KPIs, KPI-12 will also include the publications and patents from the inherited projects (of FCH JU), considering the time required to prepare, submit and publish them (especially for patents).

The important aspects of synergies and cross-sectoral solutions are captured by KPI-9 and KPI-13. Indicator KPI-10 is the only qualitative indicator of this set and monitors the progress towards the JU's specific objective on increasing public and private awareness (Article 73.2(d) of the SBA).

Table 4: Clean Hydrogen JU KPIs, monitoring the progress towards the specific objectives of its Strategy Map

Strategy Map Objective	KPI Name	Unit of measurement	Baseline	Target 2023	Target 2025	Target 2027	Ambition >2027
Outcomes							
Limiting environmental impacts	7. Environmental impact and sustainability	TBD	TBD	TBD N/A?	TBD	TBD	
Improving cost-effectiveness	8.a Capital cost of electrolyzers	€/kW	TBD	TBD N/A?	TBD	TBD	
	8.b Capital cost of heavy-duty transport applications	€/kW	TBD	TBD N/A?	TBD	TBD	
Synergies with other partnerships	9. Research and Innovation Synergies	# of projects	5	5	10	20	
Increasing Public Awareness	10. Public perception of hydrogen	Qualitative indicator	N/A	N/A	N/A	N/A	
Reinforcing EU scientific and industrial ecosystem, including SMEs	11. Total persons trained	# of persons	4,163	1,000 N/A?	3,000	6,000	
	12. Patents and publications	#of patents / publications	12 / 289	17 / 100	20 / 400	25 / 450	
	13. Promoting cross-sectoral solutions	# of projects	15	10	15	25	

9.3. IMPACTS

The third layer of indicators monitors how the actions and the outcomes of the JU contribute towards its relevant macro level objectives: Climate Action, Clean Energy and Sustainable Growth. These high-level objectives are linked also with a Key Strategic Orientation of the Horizon Europe Strategic Plan: making Europe the first digitally enabled circular climate neutral and sustainable economy, through the transformation of its mobility, energy, construction and production systems.

It is important to clarify that these KPIs report generally on the EU hydrogen sector and are not restricted to the JU activities. Their aim is to monitor how a number of high level indicators, defined at policy level (e.g. Hydrogen Strategy) and on which the JU is contributing via its activities, are progressing. The targets match – to the extent possible – the ones in the Hydrogen Strategy⁹⁶. The indicators, the associated strategic objectives, their baseline and targets are reported in Table 5 below.

The KPI on the expected avoided emissions is a critical one, but at the same time one of the most complicated to calculate. In order to properly report it, it needs to be clearly defined, boundary conditions to be properly set and the calculations steps to be clarified. Again, the determination of this KPI is not straightforward and will be determined with the assistance of experts.

The indicators KPI-15, KPI-16 and KPI-17 monitor the progress towards the certain objectives set in the Hydrogen Strategy, looking at the supply side, the demand side and the final cost to the user. Finally, KPI-18 aims to monitor in a qualitative manner how the private hydrogen sector develops.

Table 5: Clean Hydrogen JU KPIs, monitoring the progress towards the general objectives of its Strategy Map

Strategy Map Objective	KPI Name	Unit of measurement	Baseline	Target 2023	Target 2025	Target 2027	Ambition >2027
Impacts							
Reducing GHG emissions	14. Expected avoided emissions	Mt of CO ₂ -eq	TBD	N/A	N/A	N/A	TBD (2030/2050)
Energy transition with renewable hydrogen	15. Deployment of electrolyzers	Gigawatt	1	4	6	10	40 (2030)
	16. Market uptake of clean hydrogen	Mt of clean hydrogen consumed	0.155	0.7	1	2	10 (2030)
Competitive and innovative European hydrogen value chain	17. Total cost of hydrogen at end-use	€/kg	8	6.5	5.5	4.5	3 (2030)
	18. Size of private hydrogen sector	Qualitative indicator	N/A	N/A	N/A	N/A	

96. Note that some of these targets have been further enhanced in the REPowerEU Plan.

10. CONCLUSIONS AND NEXT STEPS

The Clean Hydrogen JU was setup with ambitious goals and a Programme covering the whole hydrogen value chain. Building on the legacy of FCH JU and its two successful Programmes, the JU is called on one hand to support research in the next generation of hydrogen technologies and on the other hand to increase the TRL of the best available technologies, in order to support the market uptake of hydrogen. In order to achieve its goals, it is necessary to periodically review its Programme, highlight its achievements and identify the areas where effort is needed. The annual Programme Review, as summarised in this report, serves exactly this purpose.

At the time of the drafting of this report the Clean Hydrogen JU has not signed yet any grants as part of its Call 2022. Therefore, the projects examined in this Programme Review are still the ones inherited from FCH JU and on which results it will continue the support for the next almost ten years. Section 5 highlights numerous achievements of these projects in all areas of the hydrogen value chain. Significant advancements have been achieved in the electrolyzers, where the best in the class have already met some of the 2024 KPIs, while demonstration projects have proven to be a reliable enable for sectorial integration. The demonstrations in fuel cell cars and buses show that they have achieved technological maturity and they are trying to find their place in the fast-evolving vehicle market looking for clean solutions. But also in terms of stationary applications, the demonstration projects have confirmed the performance of fuel cells for domestic applications. The next step for both of these end use applications is volume manufacturing of components, necessary to decrease costs further and make them more cost competitive. Finally, the JU exhibits a comprehensive portfolio of cross-cutting activities, supporting sustainability, circularity, education, public awareness, safety, PNR actions which are all essential for mass-market commercialization. The Clean Hydrogen JU needs to build on these results in the coming years, but also shift partially its Programme coverage towards areas that haven't been explored sufficiently.

A recurring observation of stakeholders, expressed also by the wider scientific community and noted also by JRC, is the need to invest further in cross-cutting activities, in particular in relation to RCS and skills, as these tend to become the major barriers to entry in the hydrogen market. The other often identified issue is the need to ensure the availability of resources and components in EU, by strongly supporting manufacturing capacity in EU in the coming years, while also working more on materials and related sustainability aspects.

Hydrogen valleys can play a key role in the market uptake of hydrogen, as they provide a renewable energy ecosystem where different types of stakeholders can collaborate to see the benefits of hydrogen. In practice, hydrogen valleys can demonstrate how all the different sides of using hydrogen as an energy vector fit together in an integrated system approach at a local level. They can help identify regulatory and standards bottlenecks, while increasing public awareness. If setup appropriately, based on the hydrogen demand needs of the valley participants, they can ensure proper sizing to the hydrogen uptake and address this additional bottleneck. In turn they could then provide for the creation of the necessary demand in EU for equipment and components to support in-house manufacturing.

Overall, the observations and recommendations discussed in this report will provide important feedback to the Clean Hydrogen JU, in order to analyse the progress of the Programme towards achieving its objectives and adjusting it accordingly, when necessary (in particular through the next calls for proposals).



Clean Hydrogen Partnership

ANNEX 1 – METHODOLOGY FOR CLEAN HYDROGEN JU SPECIFIC KPIS

KPI-1a Share of JU budget supporting hydrogen end-use solutions in hard to abate sectors

- Percentage of JU budget directed towards projects with direct application in the industrial and heavy-duty transport sectors.
- Percentage is calculated as cumulative JU funding for relevant projects over total JU funding up to the reference year.
- Baseline determined achievement over the lifetime of the predecessor partnership.
- Targets set in the SRIA reflecting the ambitious objectives of the JU in the context of the Green Deal.

KPI-1b Share of JU budget supporting circular and sustainable solutions

- Percentage of JU budget directed towards projects which include KPIs or objectives related to sustainability, recycling or circularity.
- Percentage is calculated as cumulative JU funding for relevant projects over total JU funding up to the reference year.
- Baseline determined achievement over the lifetime of the predecessor partnership.
- Targets set in the SRIA reflecting the ambitious objectives of the JU in the context of the Green Deal.

KPI-2 Early research projects

- Percentage of JU budget directed towards projects starting at TRL up to level 3.
- Percentage is calculated as cumulative JU funding for relevant projects over total JU funding up to the reference year.
- Baseline determined by the achievement over the lifetime of the predecessor partnership.
- Targets set in the SRIA in line with the 10% budget requirement for low TRL activities mentioned in the SRIA, Section 5.1.

KPI-3 Demonstration projects

- Number of JU projects with a goal to end at least at TRL 7.
- Number is calculated cumulatively over the JU lifetime.
- Baseline determined by the achievement over the lifetime of the predecessor partnership.
- Targets set in the SRIA based on FCH JU trends, but further enhanced considering the increased budget and new objectives.

KPI-4 Education and training

- Number of JU projects addressing education and training, including skills.
- Number is calculated cumulatively over the JU lifetime.
- Baseline determined by the achievement over the lifetime of the predecessor partnership.
- Targets set in the SRIA based on FCH JU trends, but further enhanced considering the increased budget and new objectives.

KPI-5 Monitoring technology progress

- Qualitative indicator, reporting on the actions performed related to the assessment and monitoring of technological progress, as per Article 74 (a) of the SBA.
- Due to the nature of this indicator, no targets (and thus baseline) have been set.

KPI-6 Supporting European Commission in its activities targeting the market uptake of hydrogen

- Qualitative indicator, reporting on the actions performed related to (a) JU's contribution to the development of regulations and standards, as foreseen in Article 74 (b) of the SBA, and (b) supporting the European Commission in its international initiatives on the hydrogen strategy, as foreseen in Article 74 (c) of the SBA.
- Due to the nature of this indicator, no targets (and thus baseline) have been set.

KPI-7 Environmental impact and sustainability

- Exact definition of KPI, with possibility to be split in sub-KPIs, baseline and targets to be determined with the help of experts⁹⁷.

KPI-8a Capital cost of electrolyzers

- Exact definition of KPI, with possibility to be split further in sub-KPIs, baseline and targets to be determined with the help of experts⁹⁷.

KPI-8b Capital cost of heavy-duty transport applications

- Exact definition of KPI, with possibility to be split further in sub-KPIs, baseline and targets to be determined with the help of experts⁹⁷.

KPI-9 Research and Innovation Synergies

- Number of JU projects co-funded with other Partnerships, EU Programmes, Regional and National Funds.
- Number is calculated cumulatively over the JU lifetime.
- Baseline determined by the achievement over the lifetime of the predecessor partnership.
- Targets set in the SRIA reflecting the ambitious objectives of the JU in terms of achieving synergies with other Programmes.

KPI-10 Public perception of hydrogen technologies

- Qualitative indicator, reporting on the public opinion on hydrogen technologies and associated aspects.
- The indicator will be largely based on a periodic public opinion survey⁹⁸ and the deliverables of Call 2022 topic⁹⁹.
- Due to the nature of this indicator, no targets (and thus baseline) have been set.

97. The task has been foreseen as part of the FWC to be signed by the JU with Hydrogen Europe, procedure No Clean Hydrogen/OP/Contract 332 ("Provision of data and services in support of the European Hydrogen Observatory and monitoring of the hydrogen sector").

98. The task has been foreseen as part of the procurement No FCH/OP/Contract 307 ("Public Opinion Survey").

99. Public understanding of hydrogen and fuel cell technologies, [HORIZON-JTI-CLEANH2-2022-05-01](https://ec.europa.eu/horizon-jti-cleanh2-2022-05-01).

KPI-11 Total persons trained

- Number of persons trained from projects funded by the JU.
- Number is calculated cumulatively over the JU lifetime.
- Baseline determined by the achievement over the lifetime of the predecessor partnership.
- Targets set in the SRIA based on FCH JU trends, but further enhanced considering the increased budget.

KPI-12 Patents and publications

- KPI providing reporting on two figures, one on the number of patents and one on the number of publications.
- Number is calculated cumulatively over the JU lifetime, but including also the new patents and publications of the inherited FCH JU projects.
- For patents, due to the long time required for their approval, they will also include FCH JU projects. So the number is cumulative over also the predecessor's lifetime.
- For publications they will be reported cumulatively as of 2022, with the initial publications stemming from FCH JU projects.
- In terms of methodology, there is an inherent difficulty to collect all relevant data and associate them with specific JU projects, outside from the ones reported by the projects during continuous reporting, especially if these are published after the conclusion of the grant period. This could be either because publications and patents may not clearly specify the link with a project or because the tools used to identify them (mainly through text mining) do not have access to this information.
- In order to collect this information as widely as possible, a number of sources will be used apart from the information reported in the e-Grants tool (as part of the continuous reporting), including project data collected through the Programme Review exercise, Tools for Innovation Monitoring (TIM, JRC), CORTEX, European Hydrogen Observatory¹⁰⁰ and the European Patent database. In order to address the methodology issues mentioned above, JRC will try to further enhance TIM capabilities in this respect.
- Baseline determined achievement over the lifetime of the predecessor partnership.
- Targets set in the SRIA based on FCH JU trends, but further enhanced considering the increased budget.

KPI-13 Promoting cross-sectoral solutions

- Percentage of JU budget supporting projects covering more than one area of the hydrogen value chain.
- Percentage is calculated as cumulative JU funding for relevant projects over total JU funding up to the reference year.
- Baseline determined achievement over the lifetime of the predecessor partnership.
- Targets set in the SRIA based on FCH JU trends, but further enhanced considering the increased budget and new objectives.

¹⁰⁰. The intended platform to replace FCH0.

KPI-14 Expected avoided emissions

- Exact definition of KPI, with possibility to be split in sub-KPIs, baseline and targets to be determined with the help of experts¹⁰¹.

KPI-15 Deployment of electrolyzers

- Total capacity of electrolyzers deployed in the EU.
- The KPI should also report the capacity of electrolyzers funded by the JU, as well as renewable hydrogen production by these electrolyzers (subject to data availability).
- The data will be collected from the European Hydrogen Observatory.
- Baseline based on the available data on FCHO platform.¹⁰²
- Targets based on interpolation of the 2024 and 2030 targets set in EU's Hydrogen Strategy, Communication COM(2020) 301 of 8 July 2020.

KPI-16 Market uptake of clean hydrogen

- Total quantity of clean¹⁰³ hydrogen consumed in EU in the end-use sectors or used as feedstock.
- The data will be collected from the European Hydrogen Observatory.
- Baseline based on the available data on FCHO platform.¹⁰⁴
- Targets based on interpolation of the 2024 and 2030 targets set in EU's Hydrogen Strategy, Communication COM(2020) 301 of 8 July 2020.

KPI-17 Total cost of hydrogen at end-use

- Calculation of final cost at end-use for different applications.
- Exact definition of KPI, with possibility to be split in sub-KPIs, baseline and targets to be determined with the help of experts⁹⁷.
- The data will be collected from the European Hydrogen Observatory.
- Baseline based on the available data on FCHO platform.¹⁰⁵
- Targets based on interpolation of the 2024 and 2030 targets set in EU's Hydrogen Strategy, Communication COM(2020) 301 of 8 July 2020.

101. The task has been foreseen as part of the procurement No CLEANHYDROGEN / OP / CONTRACT 320 ("European Hydrogen Observatory").

102. FCHO, Supply & Demand Annual Report, 2021

103. Definition of clean hydrogen as per the Hydrogen Strategy, unless otherwise defined in regulation.

104. For the baseline, capacity was based on the FCHO, Supply & Demand Annual Report, 2021 and Hydrogen Europe's Clean Hydrogen Monitor 2021, while a utilisation of 63% was assumed for the electrolyser capacity (based on FCH JU electrolyzers demonstration projects) and 80% for the steam methane reforming with CCS/CCU (based on the average capacity utilisation, mentioned in the Clean Hydrogen Monitor).

105. Baseline based on current estimates across various reports.

KPI-18 Size of hydrogen technologies sector

- Qualitative indicator, describing the situation of private companies active in the hydrogen sector in the context of number of companies, size, financial assets (depending on availability).
- Exact content of KPI to be determined with the help of experts⁹⁷.
- The indicator will be largely based on the input from the two contracts associated with the European Hydrogen Observatory^{97, 101}.
- Due to the nature of this indicator, no targets (and thus baseline) have been set.



Clean Hydrogen Partnership

ANNEX 2 – PROJECTS REVIEW & POSTERS

PILLAR 1 - HYDROGEN PRODUCTION

Objectives: The main technology funded under this Pillar is electrolysis. High TRL technologies such as Alkaline Electrolysers (AEL), Proton Exchange Membrane Electrolysers (PEMEL) and Solid Oxide Electrolysers (SOEL) are supported, along with newer low TRL technologies Anion Exchange Membrane Electrolysers (AEMEL) and Proton Conducting Ceramic Electrolysers (PCCEL).

The key objectives for realising the 2030 vision are:

1. Reducing electrolyser CAPEX and OPEX;
2. Improving dynamic operation and efficiency, with high durability and reliability, especially when operating dynamically;
3. Increasing current density and decreasing footprint;
4. Demonstrate the value of electrolysers for the power system through their ability to provide flexibility and allow higher integration of renewables;
5. Ensure circularity by design for materials and for production processes, minimising the life cycle environmental footprint of electrolysers;
6. Increasing the scale of deployment;
7. Improved manufacturing for both water and steam electrolysis.

Alternative hydrogen production technologies funded under this route include those using direct sunlight such as thermal dissociation of water using concentrated solar energy or through photocatalysis, biomass/biogas or other biological routes. During the reference period, two projects on alternative renewable hydrogen production routes on which the current Programme were reviewed:

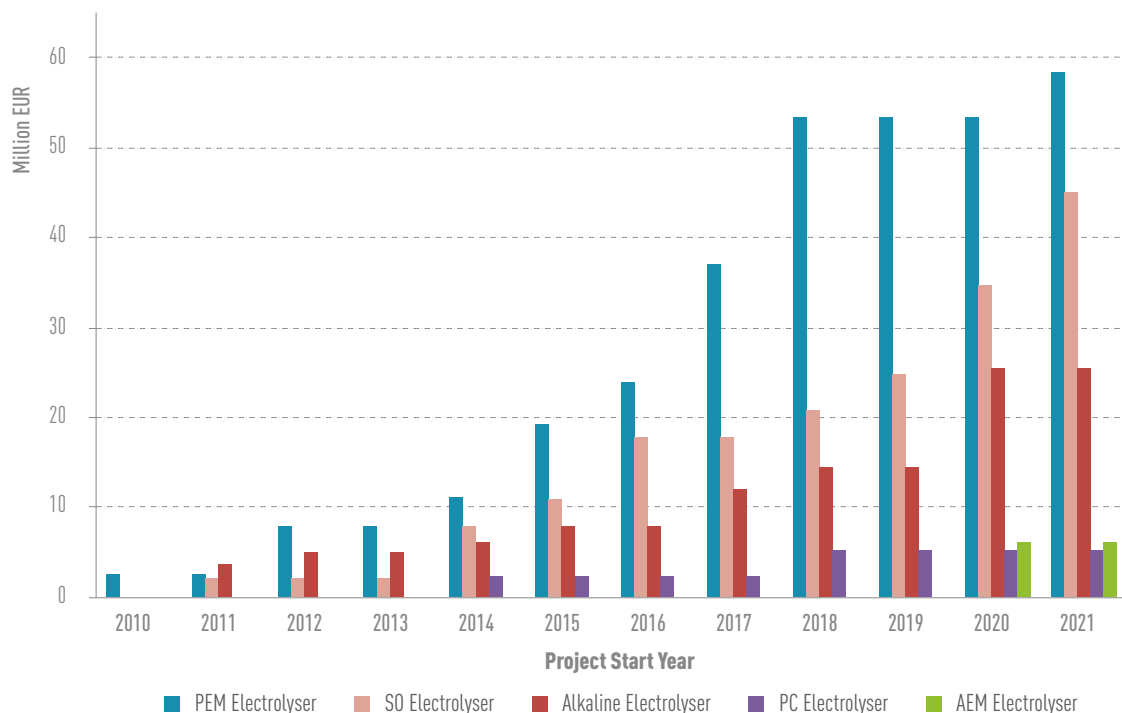
1. Raw biogas reforming for distributed hydrogen production (BIOROBURplus);
2. Thermochemical water splitting (HYDROSOL BEYOND).

The objectives for alternative hydrogen production technologies are summarised below:

1. Reducing CAPEX and OPEX
2. Improving the efficiency of processes
3. Increasing carbon yield for processes based on biomass/raw biogas (kg hydrogen / kg carbon)
4. Scaling up

Budget: PEM electrolysis has received the highest share of the funding, but support to SOEL development is increasing steadily and could reach similar levels in the future, should this trend continue, as shown in Figure 36.

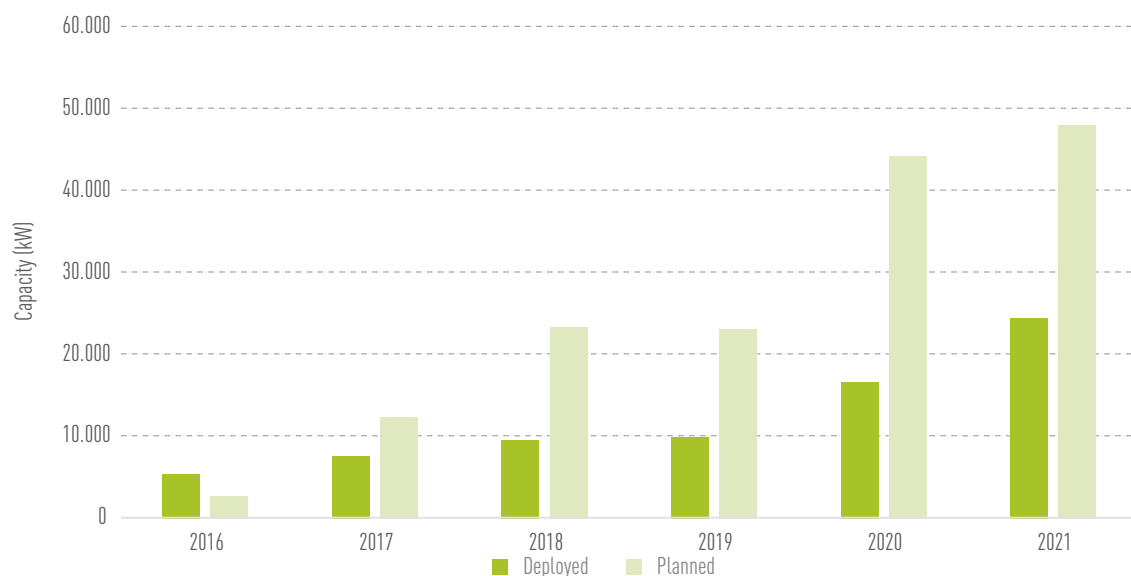
Figure 36: Cumulative Level of EU Funding Contribution for projects related to different electrolyser technologies



Source: Clean Hydrogen JU

Figure 37 shows the installed and planned electrolyser capacity of JU projects for each year until 2021. A marked increase in planned capacity can be noted starting from 2020, with deployment of more than 40 MW. Notable is the time lag between planning announcements and deployment.

Figure 37: Clean Hydrogen JU projects deployed and planned electrolyser capacity in kW per year.



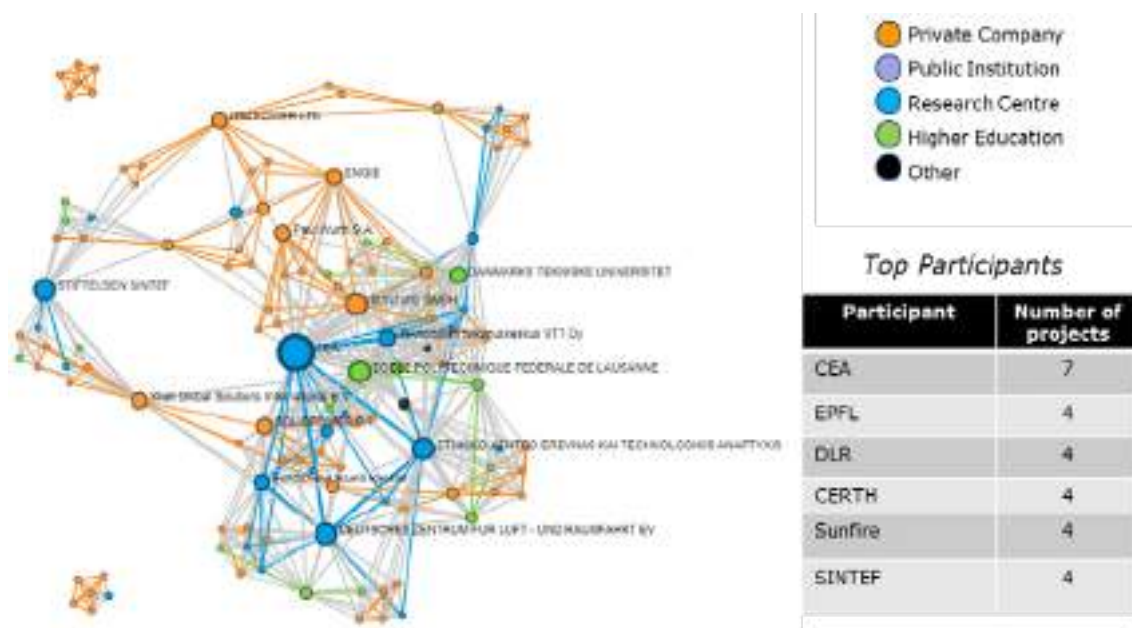
Source: Clean Hydrogen JU

Figure 38: Project timelines of Pillar 1 - Hydrogen Production. Projects highlighted in black were considered for the 2022 Assessment.



The participants in the Pillar 1 projects, often have strong links to each other. Only two AEL projects have no connections to the participants of the other project, the DJEWELS project (top left cluster) and Demo4Grid (bottom left cluster). The key participants in this panel (i.e. those present in the most projects) are dominated by research institutes (CEA, CERN, SINTEF and DLR) along with the SOEL company, Sunfire, and the Ecole Polytechnique Federale de Lausanne. This is well displayed in the TIM plot below (Figure 39).

Figure 39: TIM Plot showing the participants in the 22 projects in Pillar 1.¹⁰⁶



Source: TIM (JRC)

LOW-TEMPERATURE ELECTROLYSIS

This Research Area covers AEL, PEMEL and AEMEL. In general, there are several high TRL demonstration projects, which are demonstrating electrolyzers for a range of environments and applications. They will have tangible benefits on the future deployment of larger volumes of electrolyzers, with the overall goals of the Hydrogen Strategy in mind.

These electrolyser projects will allow to identify the bottlenecks (both technological and policy-related) and help clear the path for their more widespread deployment, especially raising awareness within industry of the capabilities of the technologies. This becomes even more urgent as the larger scale demonstrations often face significant delays, usually related to safety, permitting or other operational requirements of the industrial sites.

Eleven projects were still on-going in 2021 contributing to the development of LT Electrolyser technology (some of which have worked on both AEL and PEMEL). Further projects in other pillars (e.g. in the Hydrogen Valleys pillar, or providing hydrogen for HRS) have provided supplementary data. In addition, some projects were also asked to perform an analysis of the environmental performance of the integrated system.

ALKALINE ELECTROLYSIS (AEL)

In general, the AEL projects must further enhance their progress against the steady state performance KPI outlined in the previous MAWP. Also, projects working with AEL are often using commercial or near-commercial technologies. It is likely that not all relevant data is being submitted due to commercial sensitivity reasons.

¹⁰⁶ 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.

Grid Balancing: The commercial setup and demonstration of a 3.2 MW pressurised AEL in Austria under the project **DEMO4GRID**¹⁰⁷ is underway. Adapted to specific local conditions by providing grid-balancing services in cooperation with grid operators, the electrolyser will also supply hydrogen for fuel cell trucks (not as part of the current project) and provide heat for an industrial bakery. An assessment of potential business cases, with a focus on power-to-heat and mobility markets has been carried out. Commissioning and site acceptance test is completed and the electrolyser system is under testing phase producing its first hydrogen.

Scaling-Up: The project **DJEWELS** deploys a 20 MW electrolyser to produce 3,000 tons of green hydrogen each year, which will be combined with CO₂ to produce renewable methanol. The intention is to lay the groundwork for an eventual scale-up to a 100 MW electrolyser at the same site. The electrolyser design foresees a system energy consumption of less than 52.9 kW/kg H₂, which would be a significant contribution towards reaching the MAWP 2024 targets. The project is additionally supported by EUR 5 million in subsidies from Waddenfonds, a fund that invests in projects in the northern Netherlands. An open access hydrogen infrastructure (pipeline) will be created in the Delfzijl area, paving the way for other renewable hydrogen projects.

PROTON EXCHANGE MEMBRANE ELECTROLYSIS (PEMEL)

The EU is still playing a leading role in the development of PEMEL technologies. The Clean Hydrogen JU projects appear to have made a significant contribution towards the improvement to the SoA regarding KPIs for this technology. In this respect, the Game Changer electrolyser projects seem to be developing a next generation of potential components and materials for PEMEL.

Currently several large-scale demonstration projects are underway, there are also efforts to develop the next generation of stacks. In the section relating to Hydrogen Valleys (Pillar 6) more projects deploying multi-MW electrolysers are described. The main challenges the projects face are related to the lack of regulations and standards in the application area.

Industry decarbonisation/Grid Balancing: The project **H2FUTURE**, completed in December 2021, designed and installed a 6 MW PEMEL system at the Voestalpine steel plant in Linz and executed two years of demonstration operation of the electrolyser system, providing also ancillary grid services. From October 2020, the plant was running in a quasi-commercial mode, and it is still currently in operation. The electrolyser achieved its technical targets, including reaching a stack efficiency up to 83%, an operational range of 17-100% and the target production rate of 1,200 Nm³/h. In principle, the plant could operate on an overload capacity up to 1,500 Nm³/h, but the auxiliary equipment was not designed for this purpose. Also, by providing ancillary services, through participation in the electricity balancing market and using additional energy market options, it was possible to reduce H₂ production costs by 25-45%.

Another project is aiming to validate the business model for supplying electrolytic hydrogen to refineries¹⁰⁸. The **REFHYNE** project has deployed - and is operating since the beginning of 2022 - a 10 MW PEMEL from ITM to supply 4,000 kg of green hydrogen a day (at 20 bar pressure) to the Shell Rhineland Refinery in Wesseling, Germany. The project will also aim to mobilise additional income via the provision of primary and secondary grid balancing services. It has already contributed an assessment on policy implications and has additionally performed a detailed design study for a 100 MW electrolyser (REFHYNE 2).

Highly flexible PEMEL to link directly to on-shore/offshore renewables: The official grand opening of the site of **HAEOLUS** project took place on June 15th 2022. It includes a 45 MW wind farm in a remote area of Norway directly connected with a 2.5 MW PEMEL that can produce up to 1 tonne of hydrogen a day and is combined with a storage tank and a 120-kW fuel cell for re-electrification. The dual-stack system has now been deployed and commissioned, all the control algorithms have been defined and the demonstration is underway. It has an overload capacity of 115% and a minimum power of 5%, with a production capacity of 42 kg/h at 30 bar and 60°C, having achieved its targets for Electrolyser Efficiency and CAPEX.

107. It is building on the outcomes of the ELYGRID and ELYNTEGRATION projects

108. Refineries need hydrogen for upgrading fuels and removal of sulphur components.

In the same context, but with great expected impact, project **OYSTER** aims to develop and demonstrate in Grimsby, UK, an electrolyser suitable for fully integrated deployment with an offshore wind turbine, where the electrolyser will need to withstand a range of conditions not usually experienced by land-based electrolysers: high salinity, periods with no electricity generation, accelerations and deformations (physical motion of the offshore platform) and transportation to the site of use.

Game Changer PEM Electrolysers: The **NEPTUNE** project has assessed the market potential of high-pressure PEMEL, showing some important achievements: The degradation rate target ($< 5 \mu\text{V/h}$ at current density of 4 A/cm^2) has been achieved during a 3,500 hours test run with the final CCM. Warm start up time of less than 1 second was demonstrated. Mechanical testing of the stack design has been performed with pressures up to 180 bar. The design and testing of an advanced BoP were carried out.

The **PRETZEL** project aimed to improve on several components of the PEMEL. ATO-supported Ir anode catalysts were developed, but whilst they displayed a high level of performance in RDE tests¹⁰⁹, it was not possible to produce MEAs of sufficiently high performance or durability to carry forward into the stack testing on the lifetime of the project. Other component innovations of the project have included the development of cost-efficient VPS-coated bi-polar plates, and PTLs, tested up to 6 A/cm^2 and showed a cell efficiency of 77%.

ANION EXCHANGE MEMBRANE ELECTROLYSIS (AEMEL)

The programme demonstrates good progress regarding novel materials and components for the next generation of AEMEL. The projects are making clear efforts towards a common approach through the standardisation and harmonisation of testing protocols.

AEMEL operate in alkaline media, using a solid electrolyte. In principle, this means they can combine the use of non-platinum group metal catalysts with the production of high-purity hydrogen. Three projects were approved and funded: CHANNEL, ANIONE and NEWELY. All three projects are planned to run from 1/1/2020 to 31/12/2022. The objectives are similar: to develop high-performance, cost-effective and durable AEMEL technology.

The objective of the **CHANNEL** project is to develop a low-cost electrolyser stack and associated Balance of Plant (BoP). The project has developed and scaled up active non-PGM hydrogen and oxygen (OER) evolution reaction catalysts developed AEM ionomers and membranes for use in the 2 kW prototype. Single cell performance has achieved the project goal of 1.85 V at 1 A/cm^2 . The consortium has performed a first market analysis to investigate target markets and a preliminary cost analysis of their 2 kW stack. This is in order to develop a cost reduction strategy towards the target capital cost of $< 600 \text{ €/kW}$ for a 500 kW system. The project highlighted the possibility of several patents (regarding catalysts, ionomers, stack design etc.), of which the first (the method for production of the hydrogen evolution reaction catalyst) is about to be patented. Also, Enapter, the only manufacturer of AEMEL technology, is part of the consortium, so there should be clear possibilities for exploitation of the project results.

The project **ANIONE** is developing non-CRM catalysts and novel membranes, for application at TRL 4 for a validated 2 kW electrolyser. The project has successfully developed a highly conductive and chemically stable hydrocarbon ionomer/membrane for AEM water electrolysis with high (more than 50 mS/cm) ionic conductivity, good chemical stability $< 10\%$ loss of ion exchange capacity (IEC) after 2,000 hours in 1M KOH at 80°C , good mechanical strength and low crossover ($< 1\% \text{ H}_2$ content in the oxygen stream during electrolysis operation). They have also developed high performance, electrochemically stable NiFe oxide, oxygen evolution electrocatalysts. Subsequently, they have been able to prepare enhanced catalyst coated membrane electrode assemblies incorporating a NiMo/C cathode and NiFe oxide anode. This has demonstrated a performance of 1.7-1.8 V at 1 A/cm^2 and 50°C , plus stable performance during 2,000 hours steady state and 1,000 hours cycled ($0.2\text{-}1.0 \text{ A/cm}^2$) operations. These high performing components developed by the project and the overall improved performance need to be scaled to the 2 kW stack scale.

109. Real Driving Emissions Testing

The project **NEWELY**, the third in this grouping aims to develop a prototype five-cell stack (of 2 kW) and undergo 2,000 hours of testing. They have developed a MEA with their own catalysts but utilising a commercial membrane that achieves 2 V at 2 A/cm². They have also developed their own membrane that demonstrates sufficient conductivity but have not yet completed the 2,000 hours stability test required. They are currently in the process of scaling up from the small single cell level. The project has also completed several publications and submitted its first patent application.

The three projects in this section have coordinated a joint workshop aimed at standardisation and harmonisation of testing protocols for AEMEL, and the benchmarking of materials and components for Clean Hydrogen JU funded projects. The workshop contributed to the JRC EU harmonised protocols for the testing of low temperature water electrolyzers.

HIGH-TEMPERATURE ELECTROLYSIS

This Research Area covers mainly the SOEL technology, while PCEL technology is presented by the project GAMER. Several projects are currently at a relatively early stage.

SOLID OXIDE ELECTROLYSER PROJECTS (SOEL)

The EU appears to be maintaining a leading role with the development and commercialisation of SOEL, with both low and high TRL projects. Progress against most technical KPIs appears to have been made in the previous programme.

The increase in capacity to the MW scale is a very promising development, which helps to further establish SOEL as a competitor for the large-scale production of green hydrogen. Moreover, there are projects working on a more fundamental level, improving components to improve durability of SOEL, which seems to be one of the key remaining challenges. Also, reversibility of SOEL technology is technically interesting.

GrInHy2.0: The project demonstrates the world's biggest HT electrolyser at a capacity of 720 kW, aiming to produce more than 100 tonnes of hydrogen using steam from industrial waste heat at a Salzgitter steel mill. It has been successful in building and commissioning the electrolyser. The prototype is installed, and the production rate capacity has been increased to the full capacity of 18 kg H₂/h. By April 2022, 56 tonnes of hydrogen have been produced in 8,000 operating hours. The efficiency target of 84% LHV and 95% availability of the system has been demonstrated, and the cost target for electrolyser investment costs has been met (below 4,500 €/kgH₂/d). The target for the cost of production of green hydrogen (under 7 €/kgH₂) is yet to be achieved. Overall, the project succeeded in reaching many of its targets and it has overcome the many challenges related to operating a HT electrolyser in an industrial environment. The follow-up project MULTIPLHY will continue with stack testing.

SWITCH: The project is developing a reversible Solid Oxide Cell (rSOC) able to operate in SOEC and SOFC mode, with a capacity of 25 kW (SOFC) / 75 kW (SOEC). In SOFC mode other feedstock sources (e.g. methane, bio-methane) can be used. The prototype system consists of a rSOC-unit developed in the SWITCH project and two SOFC-units developed in the CH2P project. The SOEC mode has already been tested at single stack level and the target capacities have been achieved.

NewSOC: The project aims to advance SOEL state of the art through structural optimisation and innovative architectures, producing high performing and stable SOFC electrodes, which are to be validated as part of large cells with more than 50 cm² active area and short-stacks. The project has identified an optimum cell configuration, offering low Area Specific Resistance (ASR) and high mechanical strength¹¹⁰. The developed components will be integrated into commercial cells/stacks through the project partner Sunfire.

¹¹⁰. The highest current density has been obtained for the case of 10Sc1CeSZ based cells, ranging from 0.75 to 1.2 A/cm² (at 1.5 V, 850°C), with ASR values of 0.4 0.6 Ω/cm² and 0.45 0.7 Ω/cm² for steam and co-electrolysis respectively.

MULTIPLY: The project builds on the outcomes of the GRINHY and GRINHY2.0 projects, aiming to install and operate a 2.4 MW high-temperature electrolyser system at a biofuels refinery in Rotterdam to produce hydrogen for the refinery processes. If successful, it will advance SOEC based high-temperature electrolyser from TRL 7 to 8.

REFLEX: Following a similar concept to the SWITCH project, it is also targeting reversible Solid Oxide Cell technology, and focuses on improving rSOC components (cells, stacks, power electronics, heat exchangers).

MEGASYN: This project will perform fundamental research on cell and stack test level to improve performance, seeking to clarify degradation mechanisms. It will also design and manufacture a co-electrolyzer system at MW scale, to be integrated at a refinery. At present, the project has been successful in testing a single cell in 2,000 hours co-electrolysis operation.

PROMETEO: It has a novel approach in combining heat from Concentrating Solar Power (CSP) systems with Thermal Energy Storage (TES) to supply solar heat to a SOEL. Solar heat will be collected and stored in thermal oil or Molten Salt mixtures to balance out the fluctuation of renewable heat sources. A fully integrated and optimized system will be developed, to increase electrical efficiency higher than 85% LHV. A modular 25 kW SOEL prototype will be designed, built, connected to representative external power/heat sources and validated through tests for 1,000 hours. The project will focus on part load operation and hot stand-by periods. Techno-economic and LCA studies will be performed.

REACTT: The project is developing a Monitoring, Diagnostic, Prognostic and Control Tool (MDPC) for SOEL and rSOC stacks and systems¹¹¹. The control unit will be used to ensure optimal operation of the system, thereby increasing reliability and extending stack lifetime. The project aims to test the tool on an SOEL system and on an rSOC system. The development of the hardware platform and embedded diagnostics and prognostics algorithms is currently under way.

PROTON CERAMIC ELECTROLYSER PROJECTS (PCEL)

The project **GAMER** has advanced tubular PCCEL technology. The objective was to design a 10 kW electrolysis system, demonstrating an electrical efficiency higher than 75% Higher Heating Value (HHV), to be operated in a methanol plant with efficient thermal integration, producing pure dry pressurized hydrogen at 30 bar. A strong point is that the tubular cells can be mass produced, which will help in achieving the cost target (< 6.9 €/kg H₂). The project has made a tool available online, an engineering model enabling to describe the performance of the 10 kW system.

OTHER ROUTES OF RENEWABLE H₂ PRODUCTION

Apart from electrolysis, any other technologies are of very low TRL and only a couple of existing or just ended projects are exploring the possibilities to progress. Many technical challenges are still pending regarding the durability and stability of the materials operating at temperature over 1,000°C of the reactor in thermo-chemical hydrogen production. Also, there are not any new projects to contribute towards the SRIA KPIs.

REFORMING

The **BIOROBURPLUS** project has installed an OSR at an industrial site in Turin, which is providing the unit with biogas from anaerobic digestion. Several components have been proven in operation, such as the OSR foam catalyst, the burner unit, the compression and purification unit as well as the service units (instrument air, chilled water, gas analysis). In addition, the project has identified a few remedial measures that could prevent these

¹¹¹. Electrolyser operating modes with high current and transients could cause degradation. In order to mitigate eventual performances, a monitoring tool containing an excitation module to probe the stack with a PRBS (pseudo-random binary signal) and a control coordination unit.

problems, in case of a follow-up project. A techno-economic analysis showed that the process could, in principle, meet the H_2 production cost target, after some optimisations and for a higher production volume. Given the still low TRL of this technology and the fact that there are no other projects on this topic, it seems unlikely that the 2024 SRIA targets can be reached, despite the progress has been made.

THERMO-CHEMICAL HYDROGEN PRODUCTION

The **HYDROSOL-BEYOND** project aims to demonstrate solar thermochemical hydrogen production with a solar-to-hydrogen efficiency $>5\%$, using the existing 750kWth platform in Almeria. HYDROSOL-BEYOND is aiming to address materials and components issues encountered in the predecessor HYDROSOL-PLANT project, related to high temperature stability of materials and maintenance of custom-made components. Materials durability has been tested on 150 cycles (1,000 planned) to date. A prototype of a hybrid (metal /ceramic) heat exchanger is being manufactured at small scale, capable of operating at temperature over $1,000^\circ\text{C}$. Work is still ongoing on reaching the target of heat recovery rates of high temperature heat higher than 60% (current project achievement is 46%). Once testing is completed, the heat exchanger will be built to scale and integrated in the solar plant. It is not clear how the projects' objectives will contribute towards reaching the SRIA targets for hydrogen production rate ($2.16 \text{ kg/m}^2/\text{d}$) or cost ($15.19 \text{ kEUR}(\text{kg/d})$). A follow up project is possible, as there is a corresponding call topic in the AWP 2022, which also ask for a solar-to-hydrogen efficiency higher than 10%.

ANIONE

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



Project ID	875024
PRD 2022 Panel	1 – H2 production
Call topic	FCH-02-4-2019: New anion exchange membrane electrolyzers
Project total costs	EUR 1 999 995
Clean H ₂ max. contribution	EUR 1 999 995
Project period	1/1/2020 – 31/12/2022
Coordinator	Consiglio Nazionale delle Ricerche, Italy
Beneficiaries	Hydrolite Ltd, Université de Montpellier, PV3 Technologies Ltd, Hydrogenics Europe NV, IRD Fuel Cells A/S, Uniresearch BV, Centre national de la recherche scientifique
https://anione.eu/	

PROJECT AND OBJECTIVES

ANIONE aims to develop a high-performance, cost-effective and durable anion-exchange membrane (AEM) water electrolysis technology. The approach involves using an AEM and ionomer dispersion in the catalytic layers for hydroxide ion conduction. The project aims to validate a 2 kW AEM electrolyser with a hydrogen production rate of about 0.4 Nm³/h (TRL 4). Advanced AEMs have been developed in conjunction with non-critical raw materials (CRMs) high-surface-area electrocatalysts and membrane electrode assemblies. These advanced AEMs have shown promising performance and stability.

NON-QUANTITATIVE OBJECTIVES

- **Enhanced oxygen evolution catalysts.** ANIONE aims to develop an advanced non-CRM Ni- and Fe- based catalyst for the oxygen evolution reaction, providing reduced overpotential and enhanced stability.
- **Enhanced hydrogen evolution catalyst.** The project aims to develop an advanced non-CRM Ni-based catalyst for the hydrogen evolution reaction, providing reduced overpotential and enhanced stability.
- **Advanced cost-effective membrane.** ANIONE aims to develop cost-effective advanced AEMs with proper hydroxide ion conductivity and stability.

- **Process implementation.** The project aims to develop an AEM electrolysis operating mode providing enhanced stability.
- **AEM electrolysis hardware components.** ANIONE aims to implement advanced AEM electrolysis components in terms of diffusion layers and current collectors.

PROGRESS AND MAIN ACHIEVEMENTS

- ANIONE has developed a highly conductive and chemically stable hydrocarbon ionomer/membrane for AEM water electrolysis.
- It has developed a high-performing and electrochemically stable NiFe oxide oxygen evolution anode electrocatalyst for AEM water electrolysis.
- The project has developed enhanced-catalyst-coated-electrodes-based membrane electrode assemblies for AEM water electrolysis.

FUTURE STEPS AND PLANS

- The project will further improve AEM membrane conductivity.
- Large-area stacks will be assembled and tested.
- Promising results have been achieved with functional materials. These need to be validated at stack level.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
Project's own objectives and AWP 2019	Cell voltage at 1 A/cm ² (cell performance at 45 °C)	V	2	1.75		1.67	2020
	Degradation rate: voltage increase at 1 A/cm ²	mV/h	< 0.005	< 0.005	✓	2	2020
	Membrane conductivity	mS/cm	50 mS/cm	105	✓	80	2021

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BioROBURplus

ADVANCED DIRECT BIOGAS FUEL PROCESSOR
FOR ROBUST AND COST-EFFECTIVE
DECENTRALISED HYDROGEN PRODUCTION



Project ID	736272
PRD 2022 Panel	1 – H2 production
Call topic	FCH-02-2-2016: Development of compact reformers for distributed bio-hydrogen production
Project total costs	EUR 3 813 536.24
Clean H ₂ , max. contribution	EUR 2 996 248.74
Project period	1/1/2017 – 30/6/2021
Coordinator	Politecnico di Torino, Italy
Beneficiaries	ACEA Pinerolese Industriale SpA, EngiCer SA, Dbi – Gastechnologisches Institut gGmbH Freiberg, Karlsruher Institut Für Technologie, Hysytech SRL, Parco Scientifico Tecnologico Per L'Ambiente – Environment Park Torino SpA, UAB Modernios E-Technologijos, Ethniko Kentro Erevnas kai Technologikis Anaptyxis, Scuola universitaria professionale della Svizzera italiana, Johnson Matthey plc, Centre national de la recherche scientifique

<http://www.bioroburplus.org/>

PROJECT AND OBJECTIVES

BioROBURplus builds upon the now-closed BioROBUR (direct biogas oxidative steam reformer) project to develop a pre-commercial fuel processor delivering 50 Nm³/h (i.e. 107 kg/day) of 99.9 % hydrogen from different biogas types (landfill gas, anaerobic digestion of organic wastes, anaerobic digestion of wastewater-treatment sludges) in a cost-effective manner. The energy efficiency of the conversion of biogas into H₂ will exceed 80 % on a higher heating value (HHV) basis due to increased internal heat recovery, tailored pressure-temperature swing adsorption (PTSA) and a recuperative burner.

NON-QUANTITATIVE OBJECTIVES

- The safety level of the H₂ production plant was assessed as high in this project.
- ACEA personnel were well-trained to operate the BioROBURplus plant.
- Through successful project management,

the objectives were achieved, and the risks and deviations during the project were mitigated.

PROGRESS AND MAIN ACHIEVEMENTS

- A TRL6 demonstration unit for green H₂ production from biogas with a high degree of integration has been manufactured and installed, and is being commissioned.
- A robust catalyst for biogas reforming has been developed.
- Ceramic media with a continuous porosity gradient were developed for the catalyst support and burner.

FUTURE STEPS AND PLANS

The assessment of the process with the solutions that were suggested for the issues faced during the demonstration period is partially complete. During the final part of the demonstration period, some changes were made and better results were obtained, reaching the target efficiency level.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
Project's own objectives	Nominal H ₂ production capacity	Nm ³ /h	50		50 Nm ³ /h, with an overall efficiency of the conversion of biogas to green hydrogen of 65 %	2016
	Overall plant efficiency	%	≥ 80	✓	65	
	Production cost	€/kg	2		5	

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CHANNEL

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



Project ID	875088
PRD 2022 Panel	1 – H2 production
Call topic	FCH-02-4-2019: New anion exchange membrane electrolyzers
Project total costs	EUR 1 999 906.25
Clean H ₂ max. contribution	EUR 1 999 906.25
Project period	1/1/2020 – 31/12/2022
Coordinator	Sintef AS, Norway
Beneficiaries	Enapter SRL, Evonik Creavis GmbH, Shell Global Solutions International BV, Evonik Operations GmbH, Norges teknisk-naturvitenskapelige universitet (NTNU), Forschungszentrum Jülich GmbH

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

PROJECT AND OBJECTIVES

The CHANNEL project aims to build a cost-efficient 2 kW anion-exchange membrane (AEM) water electrolyser able to operate at differential pressure, and under dynamic operation, optimal for producing high-quality, low-cost green hydrogen from renewable energy sources. CHANNEL will conduct a techno-economic analysis and determine detailed future size and cost targets for AEM electrolyzers. It will identify markets and their requirements, establishing the production quantities essential to meet market needs, accounting for the expected cost decrease.

NON-QUANTITATIVE OBJECTIVES

- The project aims to contribute to science and technology through the submission of journal articles for publication and through conference contributions.
- The CHANNEL promotional video was released in early 2021.
- Two students from the University of St Andrews were trained and have been working on the project for 8 months to date.
- CHANNEL aims to contribute to the AEM test protocol harmonisation workshop alongside NEWELY and ANIONE.
- The transient AEM model code is to be released on a public platform (Github).

PROGRESS AND MAIN ACHIEVEMENTS

- The production of highly active and durable hydrogen and oxygen evolution reaction electrocatalysts was developed and scaled up.
- The single-cell electrolyser performance target of 1.85 V at 1 A/cm² using a non-PGM electrocatalyst was achieved.
- High performance AEMs were developed.

FUTURE STEPS AND PLANS

- A journal article based on the modelling of the transient pseudo-two-dimensional (P2D) AEM model, and simulation of electrode catalyst loading and composition as a function of KOH concentration, temperature and cell current density is in the process of being published, offering additional insight into the drivers of AEM cell performance and assisting optimisation activities.
- The model will be shared through an open-source modelling system to allow others in the research community to utilise the platform to make informed decisions on how best to optimise AEM electrolyser technologies.
- A demonstration of the preliminary AEM stack prototype will take place, as will the assembling of the preliminary stack and validation. These are in addition to finalising the stack design.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
Project's own objectives	Oxygen evolution reaction (OER) catalyst performance	mV	< 300 mV (at 10 mA/cm ² in 1 M of KOH)	237 mV in 1 M of KOH, 270 mV in 0.1 M of KOH	✓	Ir-based catalyst (250 mV at 10 mA/cm ²)	2019
	Hydrogen evolution reaction (HER) catalyst performance	mV	< 150 mV (at – 0.2 V versus Reversible hydrogen electrode (RHE))	60 mV in 1 M of KOH, 120 mV in 0.1 M of KOH	✓	Pt-based catalyst (30 mV at – 10 mA/cm ²) in 1 M of KOH	
	OER catalyst stability	mV	< 25 mV degradation over 1 000 hours in rotating disk electrode (RDE)	33 mV	⚙️	N/A	N/A
	HER catalyst stability	mV	< 25 mV degradation over 1 000 hours in RDE	26 mV	⚙️		
	Single-cell performance (at 1 A.cm ⁻²)	V	1.85	1.85	✓	1.8	2021
AWP 2019	Membrane OH ⁻ conductivity (T=RT)	mS/cm	50	< 45	⚙️	Approximately 120 (50-micron membrane from Sustainion) 40–45 mS/cm FAA-3 (Fumatech)	2020
	Ionomer OH ⁻ conductivity (temperature = 60 °C)	mS/cm	20	> 60	✓	N/A	N/A

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Demo4Grid

DEMONSTRATION OF 4 MW PRESSURIZED ALKALINE ELECTROLYSER FOR GRID BALANCING SERVICES



Project ID	736351
PRD 2022 Panel	1 – H2 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 7 736 682.5
Clean H ₂ 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, Mpreis Warenvertriebs GmbH, Instrumentación y Componentes SA, Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón, IHT Industrie Haute Technologie SA

<http://www.demo4grid.eu/>

PROJECT AND OBJECTIVES

The main aim of this project is the commercial set-up and demonstration of a technical solution utilising 'above state of the art' pressurised alkaline electrolyser (PAE) technology to provide grid-balancing services in real operational and market conditions. The ultimate goal is to provide grid-balancing services to the transmission system operator (primary and secondary balancing services). The electrolysis plant will be installed in Völs near Innsbruck.

PROGRESS AND MAIN ACHIEVEMENTS

The pressurised alkaline electrolyser was installed at the demonstration site and produced its first hydrogen on 22 March 2022.



QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
Project's own objectives	H ₂ production electrolysis, hot start from minimum to maximum power	seconds	2		60	2015
	Start-up time KPIs from cold to minimum part-load for alkaline electrolyzers	minutes	20		30	
	Minimum part-load operation targets for alkaline electrolyzers	% (full load)	20		30	
	Ramp up	% (full load)/s	7		7	
	Ramp down	% (full load)/s	10		10	

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Djewels

DELFIJL JOINT DEVELOPMENT OF GREEN WATER ELECTROLYSIS AT LARGE SCALE



Project ID	826089
PRD 2022 Panel	1 – H2 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
Clean H ₂ max. contribution	EUR 10 999 999
Project period	1/1/2020 – 31/12/2025
Coordinator	Nobian Industrial Chemicals BV, the Netherlands
Beneficiaries	McPhy Energy Italia SRL, Biomethanol Chemie Nederland BV, McPhy Energy Deutschland GmbH, Industrie de Nora SpA-IDN, Hincio SA, McPhy Energy, NV Nederlandse Gasunie

<https://djewels.eu>

PROJECT AND OBJECTIVES

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

NON-QUANTITATIVE OBJECTIVES

Safety performance: the hazard and operability analysis for the completed design has been carried out.

PROGRESS AND MAIN ACHIEVEMENTS

- The Djewels 1 design was finalised.
- An irrevocable permit was issued.
- Testing of the 1 MW stack has started.

FUTURE STEPS AND PLANS

- The stack testing and optimisation will be finished. This has been delayed and is anticipated to be completed in July 2022.
- An investment decision will be made in September 2022.
- Group breaking is expected at the end of 2022.
- Construction is expected to be completed in 2024.



QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Target achieved?
MAWP Addendum (2018–2020)	Energy consumption	kWh/kg	< 52.8	
	Degradation	%/year	0.72	
	Flexibility with degradation below 2 %/year	% of nominal power	3–110	
Project's own objectives	Nominal capacity	MW	25	

GAMER

GAME CHANGER IN HIGH TEMPERATURE STEAM ELECTROLYSERS WITH NOVEL TUBULAR CELLS AND STACKS GEOMETRY FOR PRESSURIZED HYDROGEN PRODUCTION



Project ID	779486
PRD 2022 Panel	1 – H2 production
Call topic	FCH-02-2-2017: Game changer high temperature steam electrolyzers
Project total costs	EUR 2 998 951.25
Clean H ₂ max. contribution	EUR 2 998 951.25
Project period	1/1/2018 – 31/12/2021
Coordinator	Sintef AS, Norway
Beneficiaries	Mc2 Ingenieria y Sistemas SL, Carbon Recycling International EHF, Coorstek Membrane Sciences AS, Shell Global Solutions International BV, Universitetet i Oslo, Stiftelsen Sintef, Agencia Estatal Consejo Superior de Investigaciones Cientificas

<http://www.sintef.no/projectweb/gamer/>

PROJECT AND OBJECTIVES

The GAMER project is developing a novel cost-effective tubular proton ceramic electrolyser (PCE) stack to produce pure, dry, pressurised hydrogen. The main objective of GAMER is to design, build and operate a low-cost 10 kW electrolyser system delivering at least a 30-bar output of dry H₂. The technology is based on tubular cells integrating a proton-conducting ceramic electrolyte produced using mass-manufacturing techniques.

NON-QUANTITATIVE OBJECTIVES

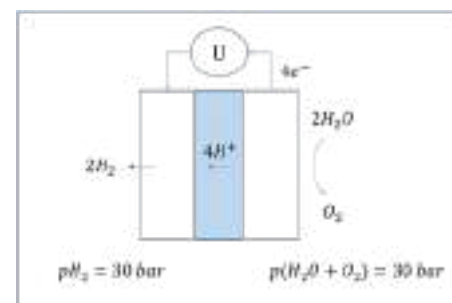
- An engineering model enabling the description of the performance of the 10 kW system was developed. The tool is available online and can be used for free. It is now used alongside other technologies in projects such as Winner.
- Several articles have been submitted and are under review. One *Nature* article has been published.
- The first stack of PCE was designed. This is thought to be the first PCE demonstration at stack level at an international scale.
- Several single engineering units (SEUs) have been tested at 600 °C at up to 10 bars, producing efficiently pressurised H₂.

PROGRESS AND MAIN ACHIEVEMENTS

- The testing of an SEU with a 60 cm² surface area at 10 bars at 600 °C was successful.
- A techno-economic analysis of GAMER technology was performed for several integration cases.
- The environmental impact of GAMER technology was assessed.

FUTURE STEPS AND PLANS

- The finalisation of racks assembly and quality assurance is in progress.
- Integration of racks in the '10 kW' testing unit and commissioning will take place. Testing will start with one rack, with the progressive integration of the other.



QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
Project's own objectives	ASR of cell at 600 °C at 3 bars in electrolysis mode	ohm.cm ²	2	2.5	⚙️	< 2	2022
	Faradaic efficiency of the SEU at 3 bars at 0.1 mA/cm ² at 600 °C	%	> 85	95	✓	> 85	2020
	Degradation rate: maximum decrease of the voltage after 500 hours at 600 °C at 100 mA/cm ²	%/h	1.2	< 5	✓	N/A	N/A
	System cost	M€	8.8	4.2–8.9	✓	N/A	N/A
	Hydrogen cost	€/kg	2.7	4.2–7.4	⚙️	N/A	N/A

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GrInHy2.0

GREEN INDUSTRIAL HYDROGEN VIA STEAM ELECTROLYSIS



Project ID	826350
PRD 2022 Panel	1 – H2 production
Call topic	FCH-02-2-2018: Demonstration of large-scale steam electrolyser system in industrial market
Project total costs	EUR 5 882 492.50
Clean H ₂ , max. contribution	EUR 3 999 993.25
Project period	1/1/2019 – 31/12/2022
Coordinator	Salzgitter Mannesmann Forschung GmbH, Germany
Beneficiaries	Paul Wurth SA, Sunfire GmbH, Salzgitter Flachstahl GmbH, Tenova SpA, Commissariat à l'énergie atomique et aux énergies alternatives

<https://salcos.salzgitter-ag.com/de/grinhy-20.html>

PROJECT AND OBJECTIVES

GrInHy2.0 is about implementing the world's biggest high-temperature electrolyser, with a capacity of 720 kW alternating current (AC) and an electrical efficiency of 84 % lower heating value (LHV). While assessing the technology's carbon direct avoidance potential for the future European steel industry, the electrolyser will produce more than 100 t of green hydrogen based on steam from industrial waste heat produced over > 13 000 operational hours by steel production in Salzgitter.

PROGRESS AND MAIN ACHIEVEMENTS

- The electrical efficiency target was reached (84 % LHV).
- The high-temperature electrolyser system's operating hours are progressing (8 000 out of 13 000 hours). By April 2022, a total of 67.6 t of hydrogen were produced in 8 000 operating hours.
- Stack degradation was below what was expected (15 mohm.cm².kh⁻¹)

FUTURE STEPS AND PLANS

- The project will achieve production of at least 100 t of hydrogen by the end of 2022. The system is currently operating normally. So far, about 56 t of green hydrogen have been produced. Provided there is steady operation, the objective will be reached by December 2022.
- A project objective is to reach 13 000 operational hours and system availability of 95 % by the end of 2022. Provided there is steady operation, this objective will also be reached by December 2022.
- The project will achieve completion of 16 000 hours of continuous stack testing by the end of 2022. The stack has reached continuous operation of 7 000 hours. Thus, the initial objective of 20 000 hours will not be reached. Provided there is steady operation, the new stack will be able to complete 15 000 hours by the end of the project.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
AWP 2018	Hydrogen production rate	kg/h	18	18	✓	3.6	2017
	Total production of green hydrogen	t	100	56	⚙️	N/A	
	Electrical efficiency based on LHV	%	84	84	✓	78	
	CAPEX	€/ (kg/d)	4 500	4 500	✓	12 000	
	Demonstration of hot start from min to max. power	minutes	5	15	⚙️	10	2018
	Hours of operation	hours	13 000	8 000	⚙️	10 000	2019
	Availability	%	95	84	⚙️	66	
	Cost of hydrogen	€/kg	7	N/A	⚙️	N/A	N/A
Project's own objectives	Hours of continuous stack testing	hours	20 000	7 000	⚙️	8 700	2019

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H2Future

HYDROGEN MEETING FUTURE NEEDS OF LOW CARBON MANUFACTURING VALUE CHAINS



Project ID	735503
PRD 2022 Panel	1 – H2 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 17 852 540.38
Clean H ₂ max. contribution	EUR 11 997 820.01
Project period	1/1/2017 – 31/12/2021
Coordinator	Verbund Energy4Business GmbH, Austria
Beneficiaries	Siemens Energy Austria GmbH, Siemens Energy Global GmbH & Co. KG, K1-MET GmbH, Verbund Solutions GmbH, voestalpine Stahl GmbH, Austrian Power Grid AG, Siemens Aktiengesellschaft Oesterreich, Stichting Energieonderzoek Centrum Nederland, Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek

<http://www.h2future-project.eu/>

PROJECT AND OBJECTIVES

The main goals of the project H2Future are to design and install a 6 MW PEM electrolyser system at the voestalpine steel plant in Linz, and to execute a 2-year demonstration operation of the electrolyser system with ambitious efficiency targets. The plant had started production by the end of 2019. While in commission, the plant has been pre-qualified to provide grid-balancing services such as primary, secondary or tertiary reserves. Since 15 October 2020, the H2Future unit is in quasi-commercial operation.

NON-QUANTITATIVE OBJECTIVES

- The project aimed to optimise production to allow the reduction of production costs by supplying ancillary services. By participating in the electricity-balancing market and by utilising additional energy market options, H₂ production costs have decreased between 25 % and 45 %.
- The project aimed to show that plant operation at overload capacity is feasible with PEM electrolysers: 50 % overload capacity was achieved during the project. However,

auxiliary units have to be designed for that purpose.

PROGRESS AND MAIN ACHIEVEMENTS

- The quasi-commercial operation phase was completed.
- The electrolyser has achieved a stack efficiency of up to 83 %.

FUTURE STEPS AND PLANS

- The plant has remained in operation since the end of the funding period of the project on 31 December 2021.
- The plant will facilitate the external delivery of the produced hydrogen by adding an upgrading unit. Some members of the project team are planning a follow-up project to supply green hydrogen for further research projects (methanation, power to liquid, etc.).
- Green hydrogen will be produced for external consumers: apart from supplying green hydrogen for research purposes, the plant will also supply it to industrial and/or mobility consumers.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	H ₂ production	Nm ³ /h	1 200	
	H ₂ purity	%	99.9	
	System efficiency at full load	%	≤ 83	✓
	Range and scalability	%	20–100	
	O ₂ purity	%	99.0	

Haeolus

HYDROGEN-AEOLIC ENERGY WITH OPTIMISED ELECTROLYSERS UPSTREAM OF SUBSTATION



HAEOLUS

Project ID	779469
PRD 2022 Panel	1 – H2 production
Call topic	FCH-02-4-2017: Highly flexible electrolyzers balancing the energy output inside the fence of a wind park
Project total costs	EUR 7 793 995
Clean H ₂ max. contribution	EUR 4 997 738.63
Project period	1/1/2018 – 31/12/2023
Coordinator	Sintef AS, Norway
Beneficiaries	Varanger KraftHydrogen AS, Varanger Krautfutvikling AS, Varanger KraftMarked AS, Varanger KraftEnterprenør AS, Varanger Kraft AS, Varanger KraftNett AS, Varanger KraftVind AS, Communauté d'universités et d'établissements Université Bourgogne Franche-Comté, New NEL Hydrogen AS, KES Knowledge Environment Security SRL, Hydrogenics Europe NV, Università degli Studi del Sannio, École Nationale Supérieure de Mécanique et des Microtechniques, Université de technologie de Belfort-Montbéliard, Fundacion Tecnalia Research & Innovation, Université de Franche-Comté, Stiftelsen Sintef

<http://www.haeolus.eu/>

PROJECT AND OBJECTIVES

The project has 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 is to test the operation of the electrolyser in different scenarios to demonstrate algorithms for energy storage, isolated grid operation and fuel production. After significant delays due to the COVID-19 pandemic, the project has received a 2-year extension and is now following the new schedule.

NON-QUANTITATIVE OBJECTIVES

The objective is to promote the 'hydrogen valley' in Finnmark. Local authorities and business stakeholders are very interested in the project. It has received additional funding from Norway to support exploitation.

PROGRESS AND MAIN ACHIEVEMENTS

- The system was deployed and commissioned.
- All control algorithms were defined.
- The demonstration has started.

FUTURE STEPS AND PLANS

Demonstration of the energy storage strategy has started and is planned to be completed by summer 2022.



QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objectives	CAPEX	M€/(t/day)	3	2	✓
	Efficiency	kWh/kg	52	52	
MAWP Addendum (2018–2020) and AWP 2017	Degradation	%/year	1.5	2	⚙️
	Cold start	minutes	0.5	20	
	Hot start	seconds	2	30	

HYDROSOL-beyond

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

Project ID	826379
PRD 2022 Panel	1 – H2 production
Call topic	FCH-02-4-2018: Thermochemical hydrogen production from concentrated sunlight
Project total costs	EUR 2 999 940
Clean H ₂ , max. contribution	EUR 2 999 940
Project period	1/1/2019 – 31/12/2023
Coordinator	Ethniko Kentro Erevnas kai Technologikis Anaptyxis, Greece
Beneficiaries	HyGear Operations BV, HyGear Hydrogen Plant BV, HyGear Technology and Services BV, EngiCer SA, Abengoa Innovacion Sociedad Anonima, HyGear Fuel Cell Systems B.V., HyGear BV, Scuola universitaria professionale della Svizzera Italiana, Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (Ciemat), Deutsches Zentrum für Luft- und Raumfahrt eV, Commissariat à l'énergie atomique et aux énergies alternatives

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


PROJECT AND OBJECTIVES

The HYDROSOL-beyond project is a continuation of the HYDROSOL-technology series of projects that 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

The objective is to develop a novel high-temperature heat exchanger. The design of a hybrid (metal/ceramic) heat exchanger capable of operating at temperatures of over 1 000 °C has been finalised and the manufacture of a small-scale prototype is in progress.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
AWP 2018	Demonstrate the process at realistic scale and working conditions, using an existing solar demonstration facility (> 200 kW range)	kW/reactor	250	N/A		250	
	Durability	cycles	1 000	150		602	2018
	Achieve heat recovery rates of high-temperature heat in excess of 60 %	%	60	46		N/A	

PROGRESS AND MAIN ACHIEVEMENTS

- Stable NiFe₂O₄ lattice structures have been produced.
- A small-scale hybrid ceramic/metallic heat exchanger has been constructed.

FUTURE STEPS AND PLANS

- The novel heat exchanger will be integrated in the existing solar platform. A small-scale apparatus has been manufactured and is being evaluated at the laboratory. The results will be taken into account for the development of the full-scale heat exchanger and its integration in the solar plant.
- The solar platform will be operated in H₂ production mode at the Plataforma Solar de Almería in Spain to run thermal tests on solar reactors.
- Data from the operation of the solar reactor at the solar simulator facility at Jülich will be available.

MegaSyn

MEGAWATT SCALE CO-ELECTROLYSIS
AS SYNGAS GENERATION FOR E-FUELS
SYNTHESIS



Project ID	101007108
PRD 2022 Panel	1 – H2 production
Call topic	FCH-02-8-2020 – Demonstration of large-scale co-electrolysis for the industrial power-to-X market
Project total costs	EUR 785 793.75
Clean H ₂ max. contribution	EUR 4 999 449.39
Project period	1/4/2021 – 31/3/2025
Coordinator	Danmarks Tekniske Universitet, Denmark
Beneficiaries	OMV Downstream GmbH, Paul Wurth SA, Sunfire GmbH, Technische Universität Graz
http://www.megasyn.eu/	

PROJECT AND OBJECTIVES

The MegaSyn project aims to install and integrate the world's first solid oxide co-electrolyser system on a MW scale at an existing refinery site. It aims to run a 2-year demonstration (12 000 hours of continuous operation) of the co-electrolyser system with a production capacity of 900 t of syngas and an availability above 95 %, while keeping the degradation rate below 1.2 %/1 000 h.

NON-QUANTITATIVE OBJECTIVES

- **Feed stream contamination.** Report on relevant contaminants and purification technologies is close to being finalised (due on 31 March 2022).
- **Designing and manufacturing of the MW-scale system.** Report on the design basis of the MegaSyn system is close to being finalised (due on 31 March 2022).

PROGRESS AND MAIN ACHIEVEMENTS

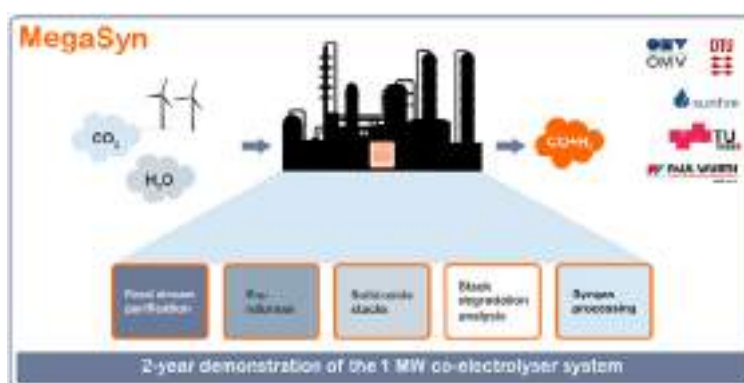
- A Sunfire single cell has been successfully tested for 2 000 hours of co-electrolysis

operation so far.

- A safety plan for handling flammable and toxic gases such as hydrogen and carbon monoxide is in place.

FUTURE STEPS AND PLANS

- Various tasks in different work plans will be carried out according to the project plan. Most of the project tasks are progressing in line with the plan.
- Detailed analysis of the 2 000-hour single-cell test will be conducted, and the identification of major degradation mechanisms and possible counteracting measures is ongoing.
- The project will design and manufacture an efficient MW-scale co-electrolyser system and demonstrate how to lower future CAPEX, and operation and maintenance costs. The design basis of the MegaSyn system needs to be revised because of the outcome of the hazard and operability analysis and safety-related issues.



QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
Project's own objective	Degradation rate	mohm. cm ² /1 000 h	17	80		30	2016

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MultiPLHY

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



Project ID	875123
PRD 2022 Panel	1 – H2 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 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	Neste Engineering Solutions BV, Neste Netherlands BV, Engie Energie Services, Neste Engineering Solutions Oy, Paul Wurth SA, Sunfire GmbH, Neste Oyj, ENGIE

<https://multiplhy-project.eu>

PROJECT AND OBJECTIVES

MultiPLHY aims to install and integrate the world's first high-temperature electrolyser (HTE) system on a multi-MW scale at a biorefinery located in Rotterdam, the Netherlands, demonstrating both technological and industrial leadership of the EU in the application of solid oxide electrolyser cell (SOEC) technology. The central element of the project is the manufacturing and demonstration of a multi-MW high-temperature electrolyser and its operation in a biorefinery. As a result, MultiPLHY promotes the SOEC based HTE from TRL 7 to 8.

PROGRESS AND MAIN ACHIEVEMENTS

- The project demonstrated stack durability for more than 7 000 hours without H₂ production loss.
- A new-generation HTE module was developed to decrease CAPEX.

FUTURE STEPS AND PLANS

Project tasks will be executed in accordance with a revised plan owing to a delay in completing some tasks. Tasks are continuously monitored regarding achievements and the timeline.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
AWP 2019	Electrical consumption	kWh/kg	85	✓	39.7	2017
	H ₂ production loss	%/1 000 h	< 1.2		1.9	
	Downtime	%	5	⚙️	N/A	N/A

NEPTUNE

NEXT GENERATION PEM ELECTROLYSER UNDER NEW EXTREMES



Project ID	779540
PRD 2022 Panel	1 – H2 production
Call topic	FCH-02-1-2017: Game changer water electrolyzers
Project total costs	EUR 1 927 335.43
Clean H ₂ max. contribution	EUR 1 926 221.25
Project period	1/2/2018 – 31/4/2022
Coordinator	ITM Power (Trading) Limited, United Kingdom
Beneficiaries	Pretexo, IRD Fuel Cells A/S, Solvay Specialty Polymers Italy SpA, ENGIE, Consiglio Nazionale delle Ricerche

<http://www.neptune-pem.eu/>

PROJECT AND OBJECTIVES

The NEPTUNE project addresses challenges associated with reducing capital costs and increasing production rates and output pressures of water electrolysis that will be required to achieve large-scale application of polymer electrolyte membrane (PEM) electrolyzers. NEPTUNE is developing a set of breakthrough solutions at material, stack and system levels to increase hydrogen pressure to 100 bars and current density to 4 A/cm² for the base load, while keeping the nominal energy consumption at < 50 kWh/kg of H₂. The novel solutions will be validated by demonstrating a robust and rapid-response electrolyser.

NON-QUANTITATIVE OBJECTIVES

The objective was to extend the protocols for testing electrolysis systems under the new operating conditions (high temperature and pressure).

PROGRESS AND MAIN ACHIEVEMENTS

- The project designed and built a new simplified balance of plant for PEM electrolysis, to extend operating conditions.
- The membrane electrode assembly (MEA) degradation rate achieved at 80 °C was 4.4 μV/h/cell at 4 A/cm² in a test lasting more than 2 000 hours (single-cell level).
- At 90 °C, cell voltages of 1.74 V at 4 A/cm² and 1.98 V at 8 A/cm² were achieved, with noble metal loading of 0.34 mg/cm² anode and 0.1 mg/cm² cathode.

FUTURE STEPS AND PLANS

- The project will seek to demonstrate the advanced cost-effective PEM electrolysis stack operating at high temperatures and with high differential pressure.
- Techno-economic assessment and life cycle analysis of the advanced PEM electrolyser will be completed shortly.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
Project's own objectives	Anode catalyst loading per W	mg/W	0.05	0.0459	✓	0.23	2018
	Cathode catalyst loading per W	mg/W	0.0071	0.0135	⚙️	0.035	
	Efficiency degradation per 1 000 hours for a low-temperature electrolyser	%/1 000 h	0.29	0.23	✓	0.2	





NEWELY

NEXT GENERATION ALKALINE MEMBRANE WATER ELECTROLYSERS WITH IMPROVED COMPONENTS AND MATERIALS

Project ID	875118
PRD 2022 Panel	1 – H ₂ production
Call topic	FCH-02-4-2019: New anion exchange membrane electrolyzers
Project total costs	EUR 2 597 413.75
Clean H ₂ max. contribution	EUR 2 204 846.25
Project period	1/1/2020 – 31/12/2022
Coordinator	Deutsches Zentrum für Luft- und Raumfahrt eV, Germany
Beneficiaries	Membranzentrum SARL, ProPuls GmbH, Cutting-Edge Nanomaterials Cenmat UG haftungsbeschränkt, Air Liquide Forschung und Entwicklung GmbH, Korea Institute of Science and Technology, Westfälische Hochschule Gelsenkirchen, Bocholt, Recklinghausen, DLR Institut für Vernetzte Energiesysteme eV, Ústav makromolekulární chemie AV ČR VVI, Fondazione Bruno Kessler, Vysoká škola chemicko-technologická v Praze, L'air Liquide SA, Commissariat à l'énergie atomique et aux énergies alternatives

<http://www.newely.eu/>

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SoA result achieved to date (by others)	Year of SoA target	
Project's own objectives and MAWP Addendum (2018–2020)	Maximum AEMWE stack size realised in the project							
	Stack power	kW	2	0.014		2.4	2021	
	Cell area	cm ²	200	4		N.A		
	Pressure	bars (relative)	≤ 40	0	✓	≤ 35		
MAWP Addendum (2018–2020)	Energy consumption @ power	kWh/kg @ W/cm ²	53.6 @ 2	53.6 @ 3.6	✓	53.6 @ 2.4	2021	
	Corresponding to cell voltage @ current	V @ A/cm ²	2 @ 1	2 @ 1.8		2 @ 1.2		
Project's own objectives and MAWP Addendum (2018–2020)	Non-PGM catalysts							
	Added overpotentials (anode and cathode)	mV	415	232		250	2020	
	Current density	mA/cm ²	1	1	✓	1		
MAWP Addendum (2018–2020) and AWP 2019	Stable operation for 2 000 hours, cell voltage gap after 2 000 hours of operation	mV	50			< 2	2021	
	Extrapolated to efficiency degradation @ rated power and assuming 8 000 hours of operation per year	Extrapolated to %/year	Extrapolated to 7.2	No test yet		< 0.3		
		Chemically, thermally and mechanically stable AEM ionomer and membrane with conductivity	mS/cm	≥ 50	62	✓	80	2021
		Area-specific resistance	ohm/cm ²	≤ 0.07	0.065	✓	0.045	

PROJECT AND OBJECTIVES

This project aims to redefine AEMWE (anion-exchange membrane water electrolysis (AEMWE), surpassing the current state of alkaline water electrolysis (WE) 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 – are addressed by three small and medium-sized enterprises and a large hydrogen company supported by seven renowned research and development centres. With a prototypic five-cell stack at elevated pressure in a 2 000-hour endurance test, twice the performance of the state of the art (SoA) of AEMWE will be validated. This will have an impact on the cost of green hydrogen.

NON-QUANTITATIVE OBJECTIVES

The techno-economic assessment and life cycle assessment demonstrate a reduction of CAPEX and OPEX for AEMWE relative to proton-exchange membrane WE and alkaline WE. Data collection is complete, and evaluation has started.

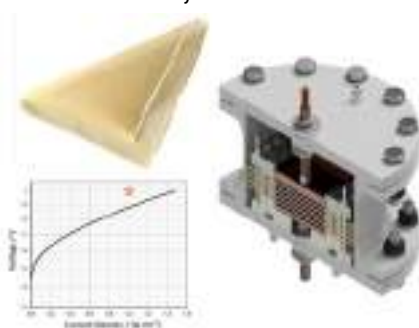
PROGRESS AND MAIN ACHIEVEMENTS

- The membrane electrode assembly (MEA) with NiFe anode, Mo₂C cathode and commercial anion-exchange membrane (AEM) / ionomer achieves 2 V at 2 A/cm² in 0.1 M KOH. No irreversible degradation was seen in a 400-hour test.
- AEM with conductivity of 60 mS/cm and area-specific resistance of 0.065 ohm/cm² was achieved.
- The project created a new method for AEM mem-

brane reinforcement with covalent bonds between the matrix and ionomer, with conductivity of 62 mS/cm.

FUTURE STEPS AND PLANS

- MEAs will be prepared at 25 cm² and 200 cm² with project materials and targeted performance. The first MEAs have been prepared; the next step is testing of the 25 cm² MEA.
- Stack design will be finalised and constructed. The first draft has already been prepared, and is awaiting the configuration of components.
- The stack has not yet been put into operation at increased pressure.
- Long-term testing of the stack will seek to demonstrate the required stability. To date, testing has been small scale; 25 cm² single-cell and in-stack testing are still to be carried out.
- Data analysis has started for the life cycle assessment and cost analysis.



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NewSOC

NEXT GENERATION SOLID OXIDE FUEL CELL AND ELECTROLYSIS TECHNOLOGY

Project ID	874577
PRD 2022 Panel	1 – H2 production
Call topic	FCH-02-6-2019 – New materials, architectures and manufacturing processes for solid oxide cells
Project total costs	EUR 2 499 992.5
Clean H ₂ max. contribution	EUR 2 499 992.5
Project period	1/1/2020 – 30/6/2023
Coordinator	Danmarks Tekniske Universitet, Denmark
Beneficiaries	Teknologian tutkimuskeskus VTT Oy, Sunfire GmbH, Ceres Power Limited, SOLIDpower SpA, Aktsiaselts Elcogen, Fundació Institut de Recerca de l'Energia de Catalunya, Hexis AG, Ethniko Kentro Erevnas kai Technologikis Anaptyxis, Instytut Energetyki, Università degli Studi di Salerno, École Polytechnique Fédérale de Lausanne, Politecnico di Torino, Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek, Commissariat à l'énergie atomique et aux énergies alternatives, Idryma Technologias kai Erevnas

<http://www.newsoc.eu/>

PROJECT AND OBJECTIVES

NewSOC aims to significantly improve the performance, durability and cost competitiveness of solid oxide cells and stacks compared with 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 (ASR), 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 project aimed to identify the electrocatalytic mechanism under solid oxide co-electrolysis cells (co-SOEC). It sought to elucidate the effect of the pH₂O and pCO₂ on the co-SOEC mechanism for the Ni/GDC fuel electrode.
- A project objective was the definition of industrial targets. Detailed numbers are to be provided by the industrial partners to guide further developments.
- The project aimed to screen potential environmental impacts. The interconnector is the largest contributor in all impact categories for both electrolyte-supported cell (ESC) and anode-supported cell (ASC) technologies.


PROGRESS AND MAIN ACHIEVEMENTS

- The project reduced the use of critical raw materials via development of a Co-free air electrode.
- It improved the cell based on the LSCr-Fe perovskite fuel electrode: the performance is not compromised by the exposure to oxidising conditions (absence of H₂).
- An interface coating was developed to improve the stability and the strength of the interface between the integrated circuit and the glass sealing to cycling operation.

FUTURE STEPS AND PLANS

- Developed components (electrodes, etc.) will be integrated into commercial cells/stacks. The identification of improved components and pairing with industrial partners have been accomplished, and the integration has started.
- Ni migration modelling to better understand the mechanism involved in the cermet degradation is in progress.
- The development of improved components will continue, with a focus on dynamic operation (cycles, redox). The development and durability assessment of candidates is in progress.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objectives	ASR (80*120 mm ² solid power anode electrolyte half-cell)	ohm.cm ² at 650 °C	0.4	0.5	
	ASR (Co-free cell, LSF oxygen electrode with improved microstructure)	ohm.cm ² at 650 °C	0.4	0.7	
	Electrolysis current for operation with degradation rate below 1 %/1 000 h	A/cm ²	0.75–1	1.2	
	Operating temperature	°C	650	650–700	

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OYSTER

OFFSHORE HYDROGEN FROM SHORESIDE WIND TURBINE INTEGRATED ELECTROLYSER



Project ID	101007168
PRD 2022 Panel	1 – H2 production
Call topic	FCH-02-6-2020: Electrolyser module for offshore production of renewable hydrogen
Project total costs	EUR 4 999 843.51
Clean H ₂ max. contribution	EUR 4 999 843
Project period	1/1/2021 – 31/12/2024
Coordinator	Element Energy, France
Beneficiaries	Ørsted Wind Power A/S, ITM Power (Trading) Limited, Siemens Gamesa Renewable Energy SA, Element Energy Limited

<https://oysterh2.eu/>

PROJECT AND 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. The project has progressed with marinisation designs and has completed the system modelling for the electrolyser's transient electronic response. Procurement exercises for the power supply unit and water treatment unit are at an advanced stage.
- It aims to deploy and test a new MW-scale electrolyser designed for marine environments for 18 months, covering all seasons.
- A project objective is to complete a design exercise of 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. Offshore wind farm sites that are expected to become available in the North Sea in the near future will be reviewed for potential dedicated offshore hydrogen production.

- 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 water treatment system design has been finalised.
- The system modelling to be used for simulation of direct connected power electronics has been finalised.
- The location for the trial has been selected. Following investigation, a trial site has been selected in Grimsby, United Kingdom.

FUTURE STEPS AND PLANS

- The project will plan and gain permits for the electrolyser trial.
- Components (offshore component, water treatment unit, power supply unit) will be procured. Due to the innovative aspects of the components, long lead times are expected – all materials are expected to be delivered by the end of 2022.
- A shoreside trial and data collection are expected to start in the second quarter of 2022.
- The trial and studies will be concluded. By combining technical developments and a shoreside test of a pilot plant with detailed studies and business case assessment for deployment at scale, this project will provide a solid foundation for implementation of the solution at scale in the 2020s.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Electrolyser footprint	m ² /MW	20	
	Maintenance cost	€/kg/year	28	
	Efficiency degradation at rated power	%/1 000 h	0.09	
	Energy consumption at rated power (system AC efficiency including balance of plant)	kWh/kg	51.6	
	Electrolyser CAPEX (at rated power), including ancillary equipment and commissioning	€/kg/day	950	
	Electrolyser CAPEX (at rated power), including ancillary equipment and commissioning	€/kW	500	
	Time for hot start (min to max power)	seconds	< 1	
	Current density	A/cm ²	3.0	
	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)	



PRETZEL

NOVEL MODULAR STACK DESIGN FOR HIGH PRESSURE PEM WATER ELECTROLYSER TECHNOLOGY WITH WIDE OPERATION RANGE AND REDUCED COST



Project ID	779478
PRD 2022 Panel	1 – H2 production
Call topic	FCH-02-1-2017: Game changer water electrolyzers
Project total costs	EUR 1 999 088.75
Clean H ₂ , max. contribution	EUR 1 999 088.75
Project period	1/1/2018 – 30/6/2021
Coordinator	Deutsches Zentrum für Luft- und Raumfahrt eV, Germany
Beneficiaries	iGas Energy GmbH, Adamant Aerodiastimikes Efarmoges Etairaia Periorismenis Efthynis, Soluciones Cataliticas Ibercat SL, Gkn Sinter Metals Filters GmbH Radevormwald, Westfälische Hochschule Gelsenkirchen, Bocholt, Recklinghausen, GKN Sinter Metals Engineering GmbH, École nationale supérieure des mines de Paris, Ethniko Kentro Erevnas kai Technologikis Anaptixis, Universitatea Politehnica Timișoara, Association pour la Recherche et le Développement des Méthodes et Processus Industriels

<https://pretzel-electrolyzer.eu/>

PROJECT AND OBJECTIVES

The overall goal of PRETZEL was to develop an innovative polymer electrolyte membrane electrolyser (PEMEL) components. The central objective was the development of a 25 kW PEM electrolysis stack, employing these innovative components, generating 4.5 m³/h of hydrogen at rated power, at 100 bars and 90 °C. The PRETZEL innovations of cost-efficient VPS-coated polar plates, high-performance titanium and stainless-steel-based porous transport layers (PTLs), among other things, have been demonstrated, reported and published. The COVID-19 pandemic caused delays, preventing the full-stack operation within the project period. The stack characterisation is ongoing.

PROGRESS AND MAIN ACHIEVEMENTS

- Regarding current density, coatings for stainless steel BPPs and PTLs were developed and tested up to a current density of 6 A/cm², achieving an unprecedented cell efficiency of 77 %.
- Regarding temperature, Ti-based PTLs allow operation of up to 6 A/cm² at 90 °C, completely eliminating mass transport limitations and passing the durability accelerated stress test.
- The 25 kW PRETZEL stack was commissioned and put in operation, reaching the target initial performance of 90 bars and 90 °C stably.

FUTURE STEPS AND PLANS

A 2 000-hour test of the PEM water electrolysis system at 90 °C, 100 bars and up to 6 A/cm² is ongoing.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Achieved to date by the project
MAWP (2014–2020) and AWP 2017	Reduce PEM electrolyser CAPEX costs: new cost-effective current collectors for PEM electrolyzers for hydrogen generation from renewable energies	Novel PTL structures allow for an unprecedented efficiency of 77 %
	Increase energy efficiency of hydrogen production: increased catalyst activity and optimisation of supporting material	Iridium-supported material (Ir/SnO ₂) has been prepared and evaluated on its catalytic activity and economic feasibility for scaling up
	Development and validation of a game-changing PEM electrolyser meeting the 2023 targets: 210 cm ² high-pressure stack with all components tested	The cell parts and computer-aided design of the high-pressure electrolyser stack have been finalised and manufactured. The design is based on partners' prototypes using the principle of hydraulic cell compression, which were developed in the publicly funded projects Vompels (EFRE-0800099) and MoDePEM (EFRE-0400094)
AWP 2017	Step-change improvements: 100 bars, rapid response (< 1 s hot start), nominal current density of 4 A/cm ² and overload of 6 A/cm ² , temperature of > 80 °C	The initial cell test for a polarisation curve up to 6 A/cm ² at 90 °C and 100 bars was successful
	Enable additional commercial roll-out of electrolyser: cost considerations and market analysis from project results extrapolated to MW scale	Market analysis started by investigating possible users of produced gases

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PROMETEO

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



Project ID	101007194
PRD 2022 Panel	1 – H2 production
Call topic	FCH-02-2-2020: Highly efficient hydrogen production using solid oxide electrolysis integrated with renewable heat and power
Project total costs	EUR 2 765 206.25
Clean H ₂ max. contribution	EUR 2 499 531.25
Project period	1/1/2021 – 30/6/2024
Coordinator	Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile, Italy
Beneficiaries	Capital Energy SL, Snam SpA, Stamicarbon BV, NextChem SpA, SOLIDpower SA, Fundación Imdea Energía, Fondazione Bruno Kessler, École Polytechnique Federale de Lausanne
https://prometeo-project.eu	

PROJECT AND OBJECTIVES

PROMETEO aims to produce hydrogen from renewable heat and power sources using solid oxide electrolysis (SOE) in areas with low electricity prices associated with photovoltaics or wind. A 25 kWe SOE prototype (approximately 15 kg/day of H₂ production) will be developed and validated in the relevant environment, combined with intermittent sources: non-programmable renewable electricity and high-temperature solar heat with thermal energy storage (TES). Partial-load operation, transients and hot standby periods will be studied.

PROGRESS AND MAIN ACHIEVEMENTS

- The project defined end users' cases.
- Preliminary process flow diagrams were created.

FUTURE STEPS AND PLANS

- The development of reduced-scale prototypes for the SOE stack and the heat storage unit combined with the steam generator to be validated in the laboratory is in progress – it is expected to be complete by the end of 2022.
- The integrated pilot plant will be designed and built. The basic design is in progress. The pilot plant is expected to be ready to operate by 2023.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Demonstrate ≥ 98 % availability of the electrolyser: hours in which the SOE has been kept at ≥ 650 °C (i.e. ready to start) versus total hours	%	98	
	Demonstrate the production of hydrogen by operation of $> 1\,000$ hours: hours of experimental validation runs of the prototype	hours	1 000	
	The SOE with renewable heat integration will demonstrate electrical efficiency of ≥ 85 % based on the LHV and specific energy consumption of < 39 kWh/kg of H ₂ in a market representative of the relevant environment: power-to-hydrogen energy conversion efficiency of the heat-integrated SOE system (LHV basis)	%	85	

REACTT

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



Project ID	101007175
PRD 2022 Panel	1 – H ₂ production
Call topic	FCH-02-3-2020: Diagnostics and control of SOE
Project total costs	EUR 2 712 322.50
Clean H ₂ max. contribution	EUR 2 712 322.50
Project period	1/1/2021 – 31/12/2023
Coordinator	Institut 'Jožef Stefan', Slovenia
Beneficiaries	Teknologian tutkimuskeskus VTT Oy, Bitron SpA, SOLIDpower SA, Haute Ecole Spécialisée de Suisse Occidentale, Università degli Studi di Salerno, AVL List GmbH, École Polytechnique Fédérale de Lausanne, Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile, Commissariat à l'énergie atomique et aux énergies alternatives

<http://www.reactt-project.eu/>

PROJECT AND OBJECTIVES

REACTT will realise a monitoring, diagnostic, prognostic and control (MDPC) tool for and 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. The development of the hardware platform and embedded diagnostics and prognostics algorithms is under way.

NON-QUANTITATIVE OBJECTIVES

- **Education/training.** The possible inclusion of the topic of SOC technologies in MSc and PhD study programmes was to be considered.
- **Public awareness.** The project web page and dissemination material are the first step towards raising public awareness.

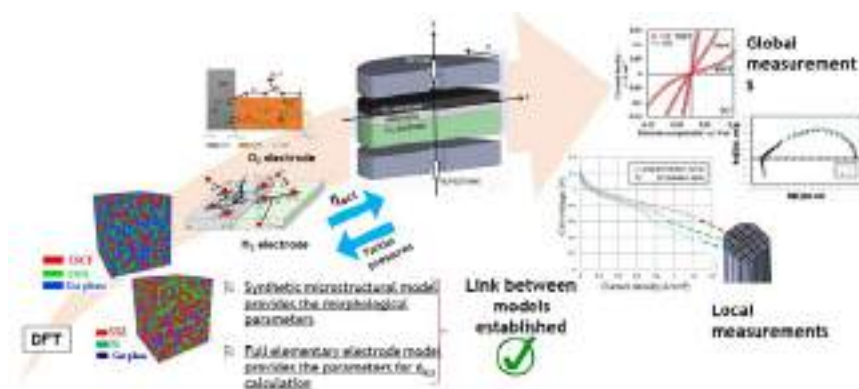
- **Safety.** Fault detection, isolation and mitigation in SOEC/ SOFC preclude process disruption and potential hazards.
- **Regulations and standards.** The formulation of a new work item proposal (NWIP) set out in M12–M36 is to be submitted to Technical Committee 105 of the International Electrotechnical Commission (IEC-TC105).

PROGRESS AND MAIN ACHIEVEMENTS

The project has developed the excitation module.

FUTURE STEPS AND PLANS

An application for a project extension has been made. Delays in stack delivery suggest delayed data acquisition from the long-term experiments under various degradation modes. The data are an important prerequisite for the design and validation of the diagnostic and prognostic algorithms.



QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Target achieved?	SoA result achieved to date (by others)
MAWP (2014–2020)	Availability	%	98		95
	Q&M cost	€/ (kg/d)/year	120	⚙️	N/A
	Electrical consumption at rated capacity	kWh/kg of H ₂	39		40–45

REFHYNE

CLEAN REFINERY HYDROGEN FOR EUROPE



Project ID	779579
PRD 2022 Panel	1 – H2 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 max. contribution	EUR 9 998 043.50
Project period	1/1/2018 – 31/12/2022
Coordinator	Sintef AS, Norway
Beneficiaries	Shell Energy Europe Limited, Shell Deutschland Oil GmbH, Sphera Solutions GmbH, ITM Power (Trading) Limited, Element Energy Limited, Stiftelsen Sintef
http://www.refhyne.eu/	

PROJECT AND 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 are installed, the plant has been tested and is ready for commissioning, and full operation will start in 2022.

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 recommending changes to existing policies.
- It aims to assess the legislative and regulations, codes and standards implications of these systems. REFHYNE will produce a detailed assessment of the consenting process for the system and any safety or codes and standards issues encountered.

PROGRESS AND MAIN ACHIEVEMENTS

- REFHYNE finalised the detailed design of the electrolyser system plant and it was adapted to the refinery.

- The permit application was approved by the local authorities.
- A 10 MW PEM electrolyser system was commissioned.

FUTURE STEPS AND PLANS

- The full operation of the electrolyser, including dynamic response testing in grid-connection mode, will begin. The system is ready for full operation. The main issue that needs to be resolved is that of timing in relation to other site activities.
- REFHYNE will undertake economic and technical analysis of electrolyser performance. Data gathering, storage and transfer to relevant partners is not 100 % ready. However, data will be stored and available for later analysis.
- The project will perform an environmental analysis of the electrolyser system and concept. The framework and models are in place, and analysis will begin once system data are available.



QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	SoA result achieved to date (by others)	Year of SoA target
Project's own objectives and MAWP Addendum (2018–2020)	Electricity consumption @ nominal capacity	kWh/kg	52	55	2020
	Capital cost	€/ (kg/day)	2 000	2 100	
	Degradation rate	%/1 000 h	0.15	0.19	
	Hot idle ramp time for H ₂ production	seconds	1	2	

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REFLEX

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

Project ID	779577
PRD 2022 Panel	1 – H2 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 , max. contribution	EUR 2 999 575.25
Project period	1/1/2018 – 31/12/2022
Coordinator	Commissariat à l'énergie atomique et aux énergies alternatives, France
Beneficiaries	Sylfen, Teknologian tutkimuskeskus VTT Oy, Engie Servizi SpA, Aktsiaselts Elcogen, Green Power Technologies SL, Parco Scientifico Tecnologico Per L'ambiente – Environment Park Torino SpA, Universidad De Sevilla, ENGIE, Danmarks Tekniske Universitet

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

PROJECT AND OBJECTIVES

The REFLEX project aims to develop an innovative renewable energies storage solution, based on reversible solid oxide cell (rSOC) technology, that can operate either in electrolysis mode, to store excess electricity to produce H₂, or in fuel cell mode, when energy needs exceed local production levels, to produce electricity and heat from H₂ or any other fuel that is locally available. It has developed improved rSOC components (cells, stacks, power electronics, heat exchangers) and defined the system, its setpoints and advanced operation strategies. An in-field demonstration will be performed in 2021.

NON-QUANTITATIVE OBJECTIVES

- The project aims to complete a techno-economic assessment.
- It aims to create an inventory of regulations, codes and standards applicable to rSOC systems in France and Italy.

PROGRESS AND MAIN ACHIEVEMENTS

- Enlarged cells were produced.
- The project has improved the stack for rSOC operation.
- The rSOC module design was completed.

FUTURE STEPS AND PLANS

- The modules and system assembly are to be finalised (ongoing).
- The installation of the system for an in-field test is planned for 2022.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
Project's own objectives	Current density in SOEC mode	A/cm ²	1.2	N/A	✓	– 1.15 A/cm ² at 750 °C, – 1 A/cm ² at 800 °C	2015–2016
	Durability in SOEC step during rSOC operation at 0.58 A/cm ² and SC= 68 %	%/1 000 h	2	1.2	✓	2.3 %/1 000 h for current densities of 0.6–0.7 A/cm ² and SC = 50 %	2015
	Cell active area	cm ²	200	200	✓	128	2021
	Power electronic efficiency	%	95	96	✓	88	2019
	Power modulation SC = 80 %	%	50–100 % SOFC, 70–100 % SOEC	58–100 % in SOEC, 13–100 % in natural-gas SOFC and 23–100 % in H ₂ SOFC	✓	57–100 % in SOEC	2019

SWITCH

SMART WAYS FOR IN-SITU TOTALLY INTEGRATED AND CONTINUOUS MULTISOURCE GENERATION OF HYDROGEN



Project ID	875148
PRD 2022 Panel	1 – H2 production
Call topic	FCH-02-3-2019: Continuous supply of green or low carbon H2 and CHP via solid oxide cell based polygeneration
Project total costs	EUR 3 746 753.75
Clean H ₂ max. contribution	EUR 2 992 521
Project period	1/1/2020 – 31/12/2022
Coordinator	Fondazione Bruno Kessler, Italy
Beneficiaries	Sweco Polska Spółka z Ograniczoną Odpowiedzialnością, SOLIDpower SA, HyGear BV, Shell Global Solutions International BV, École Polytechnique Fédérale de Lausanne, Deutsches Zentrum für Luft- und Raumfahrt eV

<https://switch-fch.eu/about/>

PROJECT AND OBJECTIVES

The SWITCH project aims to design, build and test a 25 kW (SOFC) / 75 kW (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 H₂ production technology designed for H₂-refuelling stations. The core of the system will be a reversible solid oxide cell operating in electrolysis mode (SOE) 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 development and validation of a 50 kg of H₂/day technology, realised by integrating modules composed of high-reliability stack modules provided by SOLIDpower.
- SWITCH aims to ensure that the hydrogen purity level complies with ISO 14687. Hydrogen will be purified to within the range of 99.7 % to 99.99 %, and will have a water content of less than 5 parts per million.
- 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 operation time will be 5 000 hours in the relevant environment.
- Life cycle analysis (LCA) and life cycle cost analysis (LCC) will help to evaluate the benefits of the SWITCH technology in comparison with SoA steam methane reforming (SMR) and other H₂ production technologies (electrolysis).

PROGRESS AND MAIN ACHIEVEMENTS

- The project completed the construction and testing of the solid oxide electrolysis cell (SOEC) stack in reversible operations under SWITCH modes.

- A multiperiod and multi-objective optimisation approach was adopted. This approach optimises operations over multiple periods with different characteristics in terms of pressure, temperature, flow rate and composition.
- The project determined the operating envelope of the (1 t/day) SWITCH system.

FUTURE STEPS AND PLANS

- The hazard and operability analysis (HAZOP) for the safety control of the system will be finalised. The HAZOP is in progress, and it will update the HAZOP of the CH2P prototype by revising issues such as the management of the exhaust fuel from the burner.
- The H₂ compressor in the cold balance of plant will be installed. HyGear and the supplier are discussing the interfaces to design the compressor.
- The project will finalise the piping and instrumentation diagram and update the pressure swing adsorption of the system. All vessels have been ordered and they are being delivered. The piping and instrumentation diagram for the SWITCH system is a work in progress.
- SWITCH will manufacture the hot balance of plant (BoP). All materials have been ordered. The manufacturing of the heat exchangers and the other key components is in progress. The work on the SPLC is in progress. The delta hot BoP has not started yet. The testing of the gamma hot BoP is in progress, and it will provide relevant information for building the delta hot BoP.
- In terms of the data collection for LCA and life cycle cost analysis, the LCA approach to data collection has been defined, as have the functional units that will be used for the analysis. The data collection will start in the second half of 2022.
- An exploitation workshop will be organised to start working on the business model and business plan. The project consortium will apply for Module B of the Horizon Results Booster to continue the activity related to the future exploitation of the SWITCH prototype. The focus will be on the business model and potential go-to-market strategy.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
Project's own objectives	Electrolyser conversion efficiency	%	85		80	2021
	Fuel cell conversion efficiency	%	75		80	
	Hydrogen cost	€/kg	5		11.2	2020
	Stack lifetime	hours	10 000		3 000	2021
	Low switching time	minutes	30		N/A	N/A

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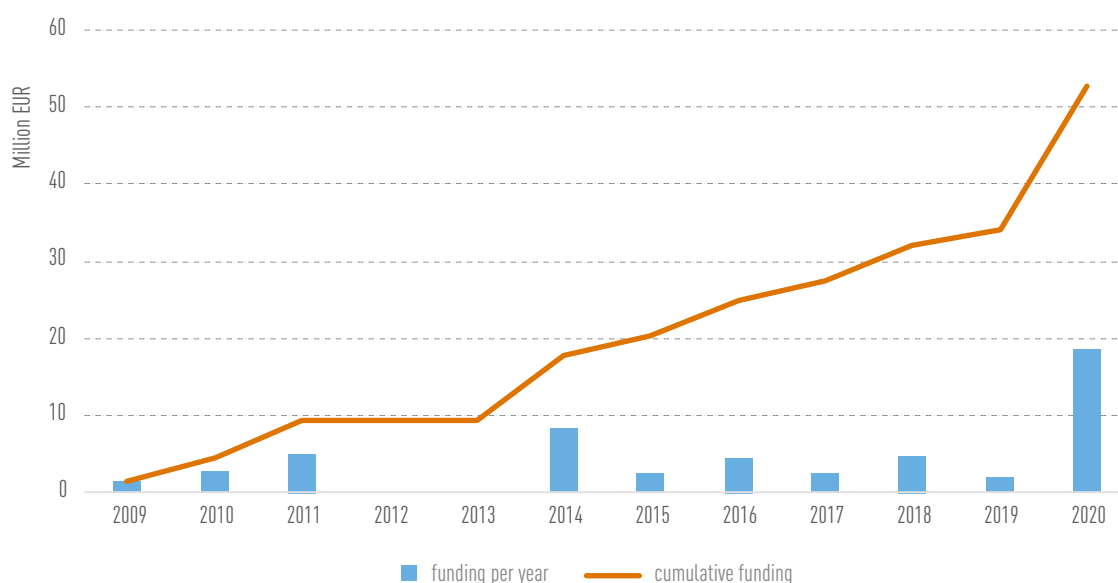


PILLAR 2 - HYDROGEN STORAGE AND DISTRIBUTION

Objectives: Pillar 2 covers many distinct technologies, for applications like storage, compression, purification/separation and delivery/transport of hydrogen. Each of these steps can be addressed by several technological options. For instance, for hydrogen storage there are various possibilities (compressed gas, liquefaction, solid state, chemical carriers, etc.), and very different scales to consider. The technologies under development are also at different levels of maturity. Therefore, the technology progress and state of the art sections are provided at research area level.

Budget: For Pillar 2, so far around EUR 52 million have been made available. The research areas underground storage and HRS have received more than 50% of the total funding. Hydrogen transport seems underrepresented, given the number of targets in the SRIA. Figure 40 shows the funding per year, which shows a marked rise due to the six Call 2020 projects.

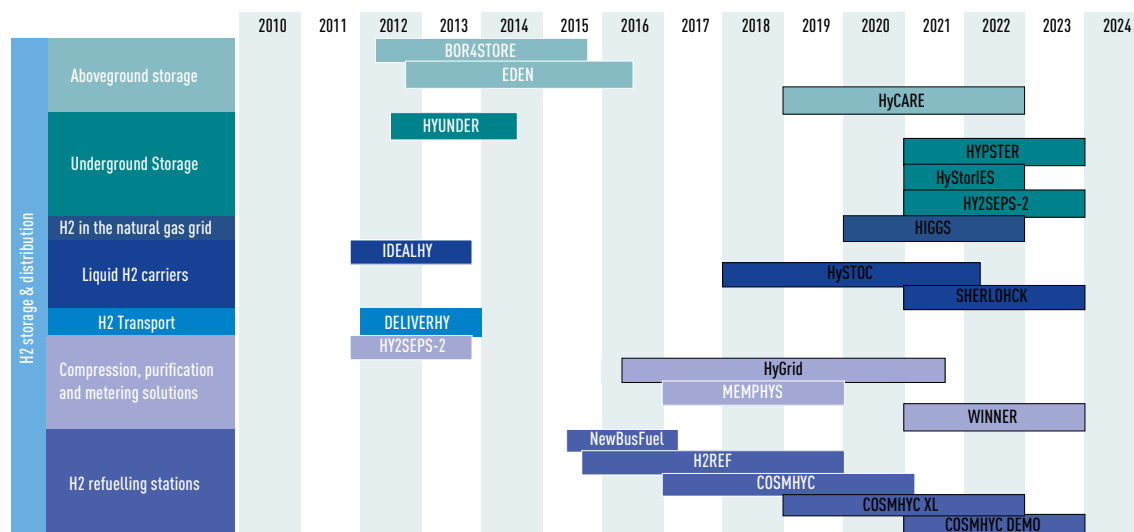
Figure 40: Funding for Pillar 2 per year, plus cumulative funding.



Source: Clean Hydrogen JU

Projects: The timeline of Pillar 2 clearly shows the increased interest in these topics, as half of the 22 projects were selected in the Call in 2018 and are part of the Programme Review of 2022 (Figure 41). In particular, underground storage is receiving renewed attention, after a long hiatus following the end of the HYUNDER project.

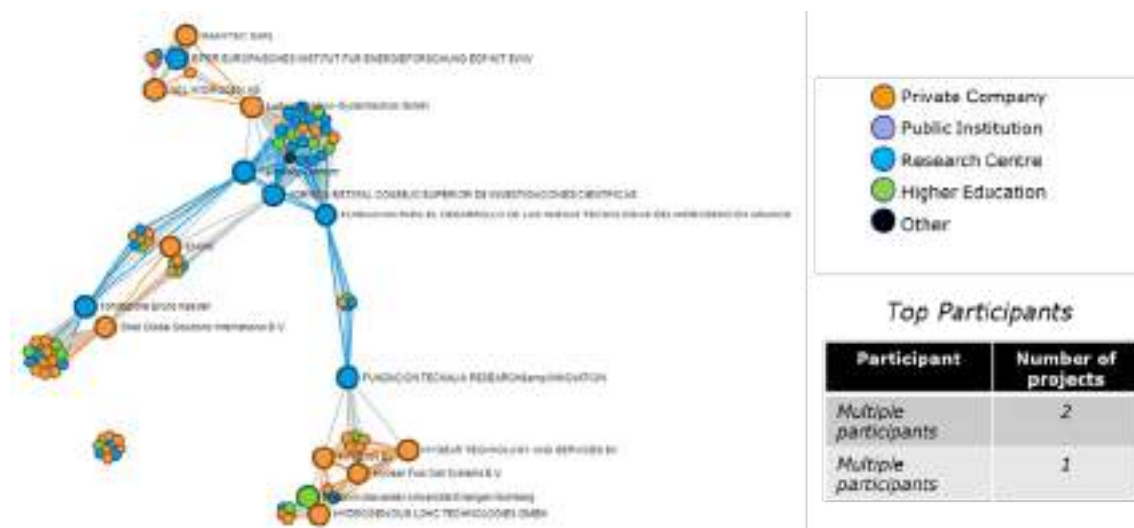
Figure 41: Project timelines of Pillar 2 – H₂ storage and distribution. Projects highlighted in black were considered for the 2022 assessment.



Source: Clean Hydrogen JU

Among the private companies, Shell, Engie, HyGear, Hydrogenious, LBST, NEL Hydrogen and MAHYTEC are the most prominent, showing a balance between large industry and SMEs. There seem to be strong links between participants, except for the project HYPSTER, which has no connections to any other project (Figure 42).

Figure 42: TIM Plot showing the participants in the 11 projects in Pillar 2.¹¹²



Source: TIM (JRC)

112. 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. The project not showing connection to others is HYPSTER.

ABOVE-GROUND STORAGE

Project **HyCARE**, following the selection and optimisation of the metal hydride material (FeTi)¹¹³, is set to start testing a large-scale hydrogen storage tank based on solid-state storage solutions. The project has implemented a heat management system with a phase change material (PCM), coupled to the metal hydride tanks (through a thermal fluid) to substantially reduce the energy demand. The testing of the small-scale prototype is completed; at present the project reports a round trip efficiency of 70%. Each tank will be able to store around 3 kg H₂, for a total of around 36 kg of hydrogen (initially 50 kg storage capacity was planned). The testing of the full-scale system follows to prove the viability of metal hydride storage systems.

UNDERGROUND STORAGE

As large scale hydrogen underground storage in salt caverns is at high TRL, the main aims of the SRIA for this topic is to reduce costs. In addition, research should be conducted for porous rock media and designs improved.

HYPSTER (2021-2023) wants to demonstrate the operation of cyclic hydrogen storage operations supporting local industrial clusters and other hydrogen consumers. The salt cavern used by the project is located in Etrez, in the Auvergne-Rhône Alpes region, in France. The project will operate a 1MW electrolyser coupled with renewable energy. The project is ongoing and has started the permitting procedure in order to finalise the construction and the use of the cavern.

While storage of pure hydrogen in salt caverns has been practiced since the 70s, storage has not yet been carried out anywhere in porous rock formations such as depleted oil and gas fields or aquifers. Research activities have been performed by nationally funded projects. Both **HYSTORIES** (2021- June 2023) and **HYUSPRE** (2021-2023) have planned a full matrix of microbiological and mechanical tests able to identify the most suitable materials and conditions for storage of hydrogen in porous rock formations. Both projects are mapping out suitable geological formations present in the European territory, are performing a legislative survey of relevant national legislation and are pursuing a full techno-economic assessment to obtain clear feasibility options for hydrogen storage in European porous formations from now until 2050. If successful, the two projects should be enabling future large demonstrations.

H₂ IN THE NATURAL GAS GRID

The **HIGGS** project aims to assess the hydrogen-readiness of gas transmission networks. As part of the experimental activities, materials and components will be tested in low, (10% vol) medium (10-30% vol) and high hydrogen (up to 100% vol) concentrations up to 80 bar pressure. Other activities include the mapping of technical, legal and regulatory barriers and enablers, techno-economic modelling of grid repurposing and the preparation of guidelines towards enabling the injection of hydrogen in high-pressure gas grids. Tests have been completed for blends of 20% vol hydrogen in natural gas. The techno-economic model is under development, but there are challenges in getting sufficient data for its validation.

LIQUID H₂ CARRIERS

The **HYSTOC** project finished in March 2022 and was successful in demonstrating a LOHC delivery chain in Finland. During the running time of the project, a total of 1,860 kg of hydrogen was transported over 500 km. This involved the hydrogenation of 39 t LOHC and dehydrogenation of 33 t LOHC. The dehydrogenation unit (ReleaseBOX) has been operated for 2,187 h in a field test, releasing around 1 200 kg hydrogen. The project has worked with the carrier dibenzyltoluene (DBT), however recent findings have revealed that benzyltoluene (BT) has advantages, regarding activity, enabling higher hydrogen release rates with less catalyst. Mixtures of DBT and BT

¹¹³. This material has a reversible gravimetric capacity of around 1.1 wt% at 55°C and between 2-20 bar and should be able to withstand more than 250 cycles.

were also investigated by the project, as these showed to be better suited to cold environments. The systems will be adapted to work with BT in the future. Following up from the project results, the company commercialising this technology, Hydrogenious, has plans to produce units capable of processing 5 tonnes H_2 /day or even larger units. Fuel cell grade hydrogen purity has been achieved, and, in collaboration with the HYDRAITE project, testing with FC has been carried out to further study the effect of contaminants (benzene and toluene). The project partners have performed tests on coupling the release system with an electrochemical compressor, which creates favourable conditions for dehydrogenation.

Lowering the energy demand of dehydrogenation is key to the **SHERLOHCK** project, that aims to develop highly active and selective catalyst material, with partial, or if possible, total substitution of PGM. There is also the target to reduce internal heat loss and increase (de-)hydrogenation conversion rate. The catalyst material will be tested in a demonstration unit (>10 kW, >200h). The project has made progress against some of the targets, the catalyst's hydrogen productivity in dehydrogenation target has reached 1.2 g H_2 /g catalyst/min (target 3 g H_2 /g catalyst/min). There are efforts underway on the integration of the catalyst material in a thermally conductive support, and the first support structures are being designed. The project also aims to assess the resistance of the catalysts to different poisons. Modelling work will support the experimental campaign. There is a link to the HYSTOC project through two partners (Hydrogenious and Friedrich-Alexander University of Erlangen), which is positive as the knowledge gained in HYSTOC will be available.

COMPRESSION, PURIFICATION AND METERING SOLUTIONS

The **HYGRID** project, finished in 2021, focused on the development and demonstration of a hybrid technology for the direct separation of hydrogen from natural gas. The hybrid approach involves a combination of membranes, electrochemical purification (EHP) and temperature swing adsorption (TSA). Membrane separation technology is to separate hydrogen from hydrogen – natural gas mixtures at a hydrogen content of 2-10% vol in a H_2 /NG blend, then in the next step EHP is used to purify the hydrogen further, and lastly the remaining humidity is removed by TSA. The main targets for the developed hydrogen separation system were an energy demand of < 5 kWh/kg H_2 and a cost for separation < 1.5 €/kg H_2 . A pilot was to be designed for > 25 kg/day of hydrogen. The key objective of the project was to demonstrate the preliminary configuration of a HYGRID system that can separate 50 kg/day of hydrogen with a purity equal to 99.999%.

The Pd-based membranes have been produced, meeting the target specifications. Carbon molecular sieve membranes (CMSM) have also been successfully tested. Very high hydrogen purities have been reached with a CMSM at lower hydrogen concentration, this seems to be the preferable option at high pressures (> 30 bar). The full-size electrochemical hydrogen EHP stack has been tested, confirming the reachability for targets such as a recovery rate of 60% for hydrogen and an energy demand of 4 kWh/kg H_2 . The pilot plant has been implemented at 12 kg H_2 /day instead of the initially planned > 25 kg H_2 /day.

HYGRID has certainly advanced separation technology solutions, but not all targets have been met. Despite some promising results, there are still some significant challenges to be overcome for this type of separation system to be realised at the planned industrial scale. The EHP seems to be sensitive to contaminants in natural gas. The energy demand of the whole system is still far higher than the target, in particular given more stringent SRIA target of 3.5 kWh/kg H_2 by 2024. The project found that in the future, energy consumption can be lowered by better heat integration/management and optimising some of the other components. With these improvements, the system can reach the energy demand target, however, this would require further development work. The project expects that the targets can be met at larger scale. The cost target, however, has already been met with the current system, which is a significant achievement.

One of the key remaining challenges is the high heat consumption required by the system, in case Pd-based membranes are used. In addition, a high amount of sweep gas is used to decrease the area of the membrane and dilute the impurities present in the initial stream.

More fundamental research will be carried out by the project **WINNER**, which started in 1/2022. The project will develop PCC for different applications. These applications are reversible electrolysis and ammonia fuel cell to power or ammonia cracking. PCC are a promising option for the compression and purification of hydrogen. The

aim is to demonstrate the flexibility of this technology. Technical objectives of the project are an ASR of the cell $<1 \text{ ohm/cm}^2$ at 650°C , which it is well on track of being reached with currently 1.4 ohm/cm^2 . A faradaic efficiency of $> 95\%$ has been measured, already accomplishing one of the project's aims. The project is facing challenges at materials level, in particular related to the preparation of thin interfacial layers, which should adhere to the electrode. Engineering models will be developed for all three applications and a new platform will be developed for multi-scale modelling.

H₂ REFUELLING STATIONS

The **COSMHYC XL** project has already achieved a high number of its objectives. Compression is a major challenge for the operation of HRS, both in terms of cost and reliability/availability of the station. A high flow rate of hydrogen is also needed. The project seeks to advance compression technology by combining mechanical with metal hydride compression, based on the outcomes of the COSMHYC project. At present, the mechanical compressor is operational ($240 \text{ kg H}_2/\text{h}$ in duplex configuration). The metal hydride compressor design is ready, including subsystems and control & monitoring system. The target for energy consumption (5 to 900 bar) is 6.18 kWh/kg H_2 , which is above the 2020 MAWP target of 5 kWh/kg H_2 (SRIA target of 4 kWh/kg H_2 by 2024). The production of the metal hydride material is on-going, and the reactors will have to be integrated with the rest of the systems. The metal hydride does not contain rare earth elements. The pre-certification of test site for the metal hydride compressor has been completed and all safety studies have been performed. Delays have been accrued due to longer delivery times of components and materials (e.g., raw material for manufacturing metal hydrides reactors). Also, the identification of the optimal composition of the metal hydride took longer than expected. It should be clarified how these delays will affect the linked project COSMHYC DEMO.

COSMHYC DEMO, which started in February 2021, is the continuation of COSMHYC XL, and both projects are linked. Regarding the selected materials, COSMHYC XL has also taken most recent experience from COSMHYC DEMO into account. From 2023 onwards, the results of COSMHYC XL will continue to be disseminated through COSMHYC DEMO. The start-up company¹¹⁴ responsible for the metal hydride compressor, which was created under COSMHYC XL, is already part of COSMHYC DEMO.

The COSMHYC DEMO project includes design, construction and integration of the metal-hydride compressor demonstrator in a new HRS with a capacity of $200 \text{ kg H}_2/\text{day}$. On the test site in France, a public hydrogen refuelling station will be installed for a variety of mobility applications. This project seeks to demonstrate the capability and flexibility of the innovative compression solution. The hybrid compressor will be used to supply hydrogen both at 350 and 700 bar. This HRS is a central part of HYSOPARC¹¹⁵, a project implemented by CCTVI (a grouping of municipalities) near Tours, France, for driving regional development based on hydrogen technologies. The HRS will supply a fleet of 700 bar passenger vehicles, 350 bar utility vehicles and a 700 bar garbage truck. The site layout plan for HRS and integration concept of compressors is finalised and the hazard and operability study for on-site installation has been completed. The metal hydride materials have been selected. There are some delays, the civil works due to problems with steel delivery, and the permit are taking more time than anticipated.

The metal hydride compressor designed in the frame of the project is to be standardized and achieve CE conformity. Many studies will be needed to get a CE certification, and the compression system has to prove its compliance with all relevant directives (such as pressure equipment and similar). These crucial steps are currently being undertaken.

114. <https://eifhytec.com/products/>

115. <http://www.tourainevalleedelindre.fr/fr/information/8511/hydrogene>

COSMHYC DEMO

COMBINED SOLUTION OF METAL HYDRIDE AND MECHANICAL COMPRESSORS: DEMONSTRATION IN THE HYSOPARC GREEN H2 MOBILITY PROJECT



Project ID	101007173
PRD 2022 Panel	2 – H2 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 costs	EUR 3 773 858.75
Clean H ₂ max. contribution	EUR 2 999 637.13
Project period	1/1/20 – 31/12/2023
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://cosmhyt.eu	

PROJECT AND OBJECTIVES

To meet the demands of a growing hydrogen economy, new technologies in the hydrogen-refuelling infrastructure – including that of 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. vehicle fleets and garbage trucks). The hybrid compressor will be used to supply hydrogen at both 350 bars and 700 bars.

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 will be 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 HRS.

PROGRESS AND MAIN ACHIEVEMENTS

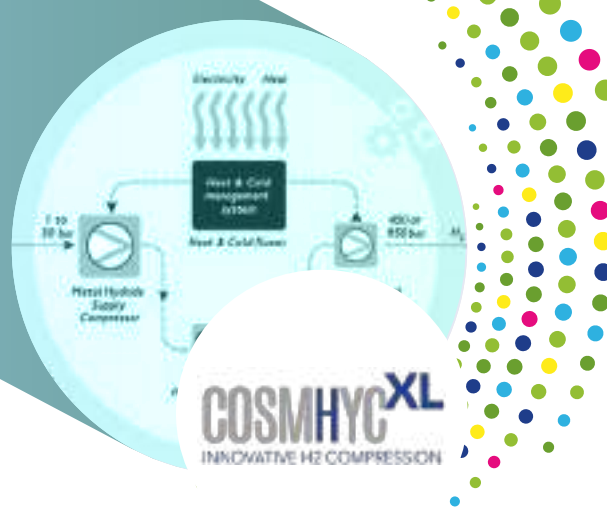
- The site layout plan for the HRS and the integration concept of compressors were finalised.
- The selection and testing of ideal rare earth-free metal hydrides for all compression stages have been successfully completed.
- A risk assessment for on-site installation was completed.

FUTURE STEPS AND PLANS

- The HRS will be installed on site. The site plan is ready, but the work has been delayed owing to supply chain issues (receiving steel from Ukraine).
- The project will obtain authorisation to integrate the metal hydride compressor into the HRS. The environmental impact study is ongoing, and the project has held good exchanges with local authorities through the advisory committee.
- Long-term tests of the demonstrator will be conducted with the on-site vehicle fleet.

COSMHYC XL

COMBINED HYBRID SOLUTION OF METAL HYDRIDE AND MECHANICAL COMPRESSORS FOR EXTRA LARGE SCALE HYDROGEN REFUELLING STATIONS



Project ID	826182
PRD 2022 Panel	2 – H2 storage and distribution
Call topic	FCH-01-7-2018: Improvement of innovative compression concepts for large scale transport applications
Project total costs	EUR 2 749 613.75
Clean H ₂ max. contribution	EUR 2 749 613.75
Project period	1/1/2019 – 31/12/2021
Coordinator	Eifer -Europäisches Institut für Energieforschung EDF – KIT EWIV, Germany
Beneficiaries	Steinbeis 2i GmbH, Mahytec SARL, Nel Hydrogen AS, Ludwig-Bölkow-Systemtechnik GmbH
https://cosmhyt.eu	

PROJECT AND OBJECTIVES

Hydrogen mobility is one of the most promising solutions for a sustainable energy transition in large-scale transport modes, including trucks, buses, trains and professional vehicle fleets. For these applications, a performant hydrogen-refuelling infrastructure is necessary, including hydrogen compressors able to meet challenging constraints in terms of flow rate and availability. COSMHYC XL aims to develop an innovative compression solution for extra-large hydrogen-refuelling stations, based on the combination of a metal hydride compressor and a mechanical compressor.

NON-QUANTITATIVE OBJECTIVES

- The project aims to create a hybrid system allowing different configurations. Ludwig-Bölkow-Systemtechnik shows that different refuelling applications require only slightly adapted configurations and intermediate storage capacities to minimise total costs.
- The project aims to increase reliability. The results of COSMHYC and the preliminary results of COSMHYC XL show that reliability can be strongly improved compared with that of SoA mechanical compressors.
- The project aims to undertake a cost of ownership assessment. There are ongoing dedicated activities within the project. The results of the previous COSMHYC project show that the target total cost of ownership can be achieved.

PROGRESS AND MAIN ACHIEVEMENTS

- A prototype of a dual-head mechanical compressor has been assembled and is operational; the compressor reaches 120 kg/h (two-stage) and 240 kg/h in duplex configuration.
- The metal hydride compressor set, including its major subsystems (e.g., thermal integration), and the control and monitoring system have been designed.
- The test site is ready for the commissioning of the metal hydride compressor prototype in a 20-foot container; all risk assessments were successfully performed and pre-certification is complete.

FUTURE STEPS AND PLANS

- The project will produce metal hydrides for all compression stages. This production is at an advanced stage.
- COSMHYC XL will integrate the innovative metal hydride compressor prototype. The container and the control and monitoring system are ready and the main subsystem is assembled; the metal hydride reactors will be completed shortly before integration in the prototype.
- The project will conduct long-term tests of the prototypes. The tests of the mechanical compressor are complete; the metal hydride compressor tests begin in early summer 2022. The testing protocol will validate the combination of the compression technologies.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
Project's own objective	Energy consumption	kWh/kg	6.18		8	2018
	Degradation	%/1 000 h	0.8		N/A	N/A
	Specific costs	k€/kg*day	1.47		3.7	2021
	Noise levels	dB	< 60		53.9	2021

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HIGGS

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



Project ID	875091
PRD 2022 Panel	2 – H2 storage and distribution
Call topic	FCH-02-5-2019: Systematic validation of the ability to inject hydrogen at various admixture levels into high-pressure gas networks in operational conditions
Project total costs	EUR 2 107 672.50
Clean H ₂ max. contribution	EUR 2 107 672.50
Project period	1/1/2020 – 31/12/2022
Coordinator	Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón, Spain
Beneficiaries	Ostschweizer Fachhochschule, Redexis Gas SA, European Research Institute for Gas and Energy Innovation, Hochschule für Technik Rapperswil, Deutscher Verein des Gas- und Wasserfaches EV – Technisch-wissenschaftlicher Verein, Fundación Tecnalia Research & Innovation
http://www.higgsproject.eu/	

PROJECT AND OBJECTIVES

HIGGS aims to fill in the gaps in knowledge of the impact that high levels of H₂ could have on high-pressure natural gas infrastructure, its components and its management. To reach this goal, the project is developing a mapping of technical, legal and regulatory barriers and enablers; testing materials/components; completing techno-economic modelling; and preparing a set of conclusions as a pathway towards enabling the injection of hydrogen into high-pressure gas grids. The inventory of materials/equipment and the regulations, codes and standards (RCS) are mostly completed, tests are ongoing and the techno-economic model is under development.

NON-QUANTITATIVE OBJECTIVES

- The project aims to draw up RCS recommendations. The first screening has been completed, and the work is ongoing.
- A pathway for stepwise integration of hydrogen into the EU gas network is being drafted.
- The project aims to develop a techno-economic model and study of the roles of technologies for integrating H₂/CH₄ and sector coupling at EU level. This work has started with the Trans Europa Naturgas Pipeline and the Mittel-Europäische-Gasleitung Pipeline

PROGRESS AND MAIN ACHIEVEMENTS

- The testing platform has enabled dynamic and static tests to be carried out.
- The project has adapted the techno-economic model.

- A system has been created for separating low concentrations of hydrogen in natural gas.

FUTURE STEPS AND PLANS

- The project will complete all experimental campaigns in the testing platform and characterisation of materials before and after hydrogen exposure to evaluate the effect of the injection of this gas. The first experimental campaign has been completed.
- An experimental campaign with the gas separation prototype is ongoing.
- The RSC review at European and national levels was collected, reviewed and compiled in a comprehensive report comprising diagrams and graphs that are to be presented on the project website and used for presentations and papers. The first review was shared publicly.
- The project will finalise a baseline definition and studies of cases regarding hydrogen blending of natural gas. This will involve simulation of these cases and analysis of techno-economic aspects.
- Work has started with the Trans Europa Naturgas Pipeline and Mittel-Europäische-Gasleitung Pipeline. The project will develop and describe a pathway towards integrating hydrogen into the EU gas networks, including proposals at national level (EU-26+). This is ongoing work that will finish with the publication of four publicly available reports.
- The main and final report will be the pathway description, due to be delivered by the end of 2022. The results are intended to be used beyond the project period.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objectives	Blending percentage compatible with existing gas transmission networks	%	Technical compatibility of materials and equipment in transmission networks	Trials with 20 % hydrogen content	
	Readiness of gas transmission networks for H ₂ distribution	%	Identify existing assets and their readiness for hydrogen transport	First inventory of the European grid	
	Techno-economic approach for grid repurposing	%	Model started	Model parameters defined in first internal deliverable	

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HYCARE

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

Demonstrator



Project ID	826352
PRD 2022 Panel	2 – H ₂ storage and distribution
Call topic	FCH-02-5-2018: Hydrogen carriers for stationary storage of excess renewable energy
Project total costs	EUR 1 999 230
Clean H ₂ max. contribution	EUR 1 999 230
Project period	1/1/2019 – 31/12/2021
Coordinator	Università degli Studi di Torino, Italy
Beneficiaries	Stühff GmbH, Tecnodelta SRL, GKN Sinter Metals Engineering GmbH, Parco Scientifico Tecnologico per l'Ambiente – Environment Park Torino SpA, Institut für Energietechnik, Helmholtz-Zentrum Hereon GmbH, Fondazione Bruno Kessler, ENGIE, Centre national de la recherche scientifique

<https://hycare-project.eu/>

PROJECT AND OBJECTIVES

The main objective of the HyCARE project is the development of a prototype hydrogen storage tank using a solid-state hydrogen carrier on a large scale. The tank will be based on an innovative concept, joining hydrogen and heat storage, to improve the energy efficiency of the whole system. The developed tank will be joined with a PEM electrolyser as the hydrogen provider, and a PEM fuel cell as the hydrogen user at the ENGIE CRIGEN laboratory, located in Île-de-France. The system is under construction and will be tested by the end of 2022.

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 via phase change materials (PCMs).

PROGRESS AND MAIN ACHIEVEMENTS

- The composition of the metal hydride has been defined and characterised. The PCM has been selected. Materials are available for the demonstrator.
- The metal hydride and PCM tank design have been finalised. A draft of the piping and instrumentation diagram of the demonstrator is available. A prototype system has been built and tested. The system is under construction.
- The site for the demonstrator has been prepared. The electrolyser and fuel cell have been commissioned and are being set up. The techno-economic and life cycle assessments have been organised. Dissemination and exploitation are active.

FUTURE STEPS AND PLANS

- The project will set up and test the final demonstrator. These activities are under way. The results are expected in December 2022.
- The obtained results will be analysed using techno-economic and life cycle assessments, and possible use of these results will be explored.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objectives	Volumetric capacity of H ₂ carrier	kg of H ₂ per unit of volume of carrier	N/A	Reversible capacity at 55 °C between 1 and 25 bars is less than 70	
	Gravimetric capacity of H ₂ carrier	% of H ₂ weight in the carrier		Reversible capacity at 55 °C between 2 and 20 bars is 1.1	
	Hydrogen storage capacity	Maximum amount of H ₂ in kg that can be stored in the system	< 50	Estimated reversible capacity at 55 °C between 1 and 25 bars is 44	
	Max. tank pressure	Pressure rating of the H ₂ carrier tank in bars		40	✓
	Cyclability	Number of full cycles until reaching 2 % reduction in the gravimetric capacity of the H ₂ carrier		250	✓

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HYGRID

FLEXIBLE HYBRID SEPARATION SYSTEM FOR H₂ RECOVERY FROM NG GRIDS



Project ID	700355
PRD 2022 Panel	2 – H ₂ storage and distribution
Call topic	FCH-02.5-2015: Development of technology to separate hydrogen from low-concentration hydrogen streams
Project total costs	EUR 3 167 710
Clean H ₂ max. contribution	EUR 2 527 710
Project period	1/5/2016 – 30/8/2021
Coordinator	Technische Universiteit Eindhoven, the Netherlands
Beneficiaries	Nortegas Energia Distribucion SA, HyGear Technology and Services BV, HyET Hydrogen BV, Quantis, HyGear Fuel Cell Systems BV, HyGear BV, Saes Getters SpA, Fundación Tecnalia Research & Innovation
http://www.hygrid-h2.eu/	

PROJECT AND OBJECTIVES

The key objective of the HyGrid project was the design, scale-up and demonstration in industrially relevant conditions of a novel membrane-based hybrid technology for the direct separation of hydrogen from natural gas grids. The focus of the project was hydrogen separation through a combination of membranes, electrochemical separation and temperature swing adsorption to decrease the total cost of hydrogen recovery. The project targets a pure hydrogen separation system with a power of < 5 kWh/kg of H₂ and a cost of < 1.5 €/kgH₂. A pilot was designed for > 25 kg/day of hydrogen.

NON-QUANTITATIVE OBJECTIVES

The project aims to train PhD students. One student has already completed their PhD and found a job in a research centre to work on topics related to HyGrid.

PROGRESS AND MAIN ACHIEVEMENTS

- All prototype parts have been completed, installed/debugged and tested at TRL5.
- Two patent applications for membranes and systems for hydrogen separation have been granted.
- Several scientific papers on all components of the prototype have been published.

FUTURE STEPS AND PLANS

The project finished in 2021.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
AWP 2015	Pure hydrogen separation system with low power	kWh/kg H ₂	5	5	
	Pure hydrogen separation system with low cost	€/kg of H ₂	1.5	1.5	✓
	Prototype unit	TRL	5	5	
	Pure hydrogen production	kg/day	25	12	⚙️

HYPSTER

HYDROGEN PILOT STORAGE FOR LARGE ECOSYSTEM REPLICATION



Project ID	101006751
PRD 2022 Panel	2 – H2 storage and distribution
Call topic	FCH-02-7-2020: Cyclic testing of renewable hydrogen storage in a small salt cavern
Project total costs	EUR 15 514 301.73
Clean H ₂ max. contribution	EUR 4 999 999
Project period	1/1/2021 – 31/12/2023
Coordinator	Storengy SAS, France
Beneficiaries	ESK GmbH, Element Energy, Storengy SA, Inovyn ChlorVinyls Limited, Axelera – Association Chimie-Environnement Lyon et Rhone-Alpes, Element Energy Limited, Ecole Polytechnique, Institut National de l'Environnement Industriel et des Risques, Association pour la Recherche et le Développement des Methodes et Processus Industriels
https://hypster-project.eu/	

PROJECT AND OBJECTIVES

HypSTER aims to demonstrate the industrial-scale operation of cyclic hydrogen storage in salt caverns to support the emergence of the hydrogen energy economy in Europe in line with Hydrogen Europe's overall roadmapping. The cavern is located in Etrez in Auvergne-Rhône-Alpes in France. For the production of green hydrogen, the Etrez storage site will rely on local renewable energy sources and a 1 MW PEM electrolyser. In the long run, this facility will produce 400 kg of hydrogen per day (the equivalent of the consumption of 16 hydrogen buses).

PROGRESS AND MAIN ACHIEVEMENTS

- The subsurface materials for hydrogen salt cavern storage have been selected.
- 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.

FUTURE STEPS AND PLANS

- The project will construct the hydrogen production platform. Building of the H₂ production platform is due to commence in April 2022.
- The project will modify the EZ53 salt cavern. Workover of the EZ53 cavern is planned for November 2022.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Electrolyser's power	MW	1	
	H ₂ mass	kg	2 000	
	CAPEX	€/kg	450	
	OPEX	€/kg	1	

HYSTOC

HYDROGEN SUPPLY AND TRANSPORTATION USING LIQUID ORGANIC HYDROGEN CARRIERS



Project ID	779694
PRD 2022 Panel	2 – H2 storage and distribution
Call topic	FCH-02-6-2017: Liquid organic hydrogen carrier
Project total costs	EUR 2 499 921.25
Clean H ₂ max. contribution	EUR 2 499 921.25
Project period	1/1/2018 – 31/3/2022
Coordinator	Hydrogenious LOHC Technologies GmbH, Germany
Beneficiaries	HyGear Operations BV, Teknologian tutkimuskeskus VTT Oy, HyGear Technology and Services BV, Oy Woikoski AB, HyGear Fuel Cell Systems BV, HyGear BV, Friedrich-Alexander-Universität Erlangen-Nürnberg

<https://hystoc.eu/>

PROJECT AND OBJECTIVES

The HySTOC project will demonstrate the liquid organic hydrogen carrier (LOHC)-based distribution of high-purity hydrogen (ISO 14687-2:2021) to a customer (Teknologian tutkimuskeskus VTT) in Finland. The H₂ is produced in and provided from Kokkola, Finland, by the project partner Woikoski. The StorageBox was placed in Kokkola by the project partner Hydrogenious. Hydrogen is bound into an LOHC. The StorageBox is operated by Woikoski with remote support from HyGear. The hydrated material is transported to the project partner VTT in Espoo, Finland. The ReleaseBox was placed in Espoo by HyGear. In the dehydrogenation process of the ReleaseBox, hydrogen is released from the LOHC.

NON-QUANTITATIVE OBJECTIVES

- HySTOC aims to build further experience of the development, assembly, commissioning, operation, costs, etc. of the LOHC hydrogenation unit. It aims to provide input for upscaling and remote access.
- It aims to build further experience of the development, assembly, commissioning,

operation, costs, etc. of the LOHC dehydrogenation unit. It aims to provide input for upscaling and remote access.

- It aims to build further experience of LOHC transport technologies.
- The project aims to improve the gas quality and reduce hydrogen loss.

PROGRESS AND MAIN ACHIEVEMENTS

- The StorageBox has been developed, built, assembled and commissioned. Currently, it is located in Kokkola and operated by project partners Woikoski and Hydrogenious.
- The ReleaseBox has been developed, built and assembled, and is almost ready to be commissioned. Currently, it is located in Espoo and final commissioning will be undertaken by VTT, HyGear and Hydrogenious.
- The pressure swing adsorption was developed.

FUTURE STEPS AND PLANS

The project finished in March 2022.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objectives	Reduction of hydrogen storage costs				
	Absolute material costs of the StorageBox	€/ (kg/d)	336 000	350 000	
	Reduction of hydrogen release costs				
	Absolute material costs of the ReleaseBox	€/ (kg/d)	400 000	380 000	✓
	Accessible to mobile applications				
	Hydrogen quality	–	ISO 14687-2:2012	ISO 14687-2:2012	✓
	Accessible to mobile applications				
	Operation time of the StorageBox	hours	2 160	2 167	✓
	Operation time of the ReleaseBox	hours	2 160	2 167	✓

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HYSTORIES

HYDROGEN STORAGE IN EUROPEAN SUBSURFACE



Project ID	101007176
PRD 2022 Panel	2 – H2 storage and distribution
Call topic	FCH-02-5-2020 – Underground storage of renewable hydrogen in depleted gas fields and other geological stores
Project total costs	EUR 2 499 911.75
Clean H ₂ max. contribution	EUR 2 499 911.75
Project period	1/1/2021 – 31/12/2022
Coordinator	Geostock SAS, France
Beneficiaries	MicroPro GmbH, Norwegian Research Centre AS, UK Research and Innovation, Ludwig-Bölkow-Systemtechnik GmbH, Réseau d'excellence européen sur le stockage géologique de CO ₂ , Geoinżyniering družba za geološki inženiring DOO, Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón, Sveučilište u Zagrebu Rudarsko-geološko-naftni fakultet, Geologische Bundesanstalt, Universidade de Évora, Institut royal des sciences naturelles de Belgique, Instytut Gospodarki Surowcami Mineralnymi i Energią Polskiej Akademii Nauk, Ethniko Kentro Erevnas Kai Technologikis Anaptyxis, Geological Survey of Denmark and Greenland, Institutul Național de Cercetare-Dezvoltare Pentru Geologie și Geoecologie Marina-Geocomar, Główny Instytut Górnictwa, Česká Geologická Služba, Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Middle East Technical University, Tallinna Tehnikaülikool, Montanuniversität Leoben, Agencia Estatal Consejo Superior de Investigaciones Científicas, Helmholtz-Zentrum Potsdam – Deutsches GeoForschungsZentrum, Bureau de Recherches Géologiques et Minières

<http://www.hystories.eu/>

PROJECT AND OBJECTIVES

Although storing pure hydrogen in salt caverns has been practised in Europe since the 1970s, no pure hydrogen storage in depleted fields or aquifers has been undertaken. Hystories will deliver technical developments applicable to a vast range of future aquifer or depleted field sites, conduct techno-economic feasibility studies and provide insights into underground hydrogen storage for decision-makers in government and industry. The project started on 1 January 2021 and is now 60 % complete.

PROGRESS AND MAIN ACHIEVEMENTS

- The project has made technological developments for pure hydrogen storage in depleted fields and aquifers.

- It has gained techno-economic insights on the development of underground storage of hydrogen.

FUTURE STEPS AND PLANS

- Hystories will catch up on the delayed implementation of the work; the focus is on completing this ambitious project on time.
- The main technical development analyses are complete: the key preliminary results have been obtained and the hydrogen storage needed by the European energy system has been identified. The remaining tasks related to the techno-economic assessments are ready to be carried out.
- The technical developments and techno-economic analyses are complete; the focus is on elaboration of the final implementation plan.



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HYUSPRE

HYDROGEN UNDERGROUND STORAGE IN POROUS RESERVOIRS



Project ID	101006632
PRD 2022 Panel	2 – H2 storage and distribution
Call topic	FCH-02-5-2020: Underground storage of renewable hydrogen in depleted gas fields and other geological stores
Project total costs	EUR 3 714 850
Clean H ₂ max. contribution	EUR 2 499 850
Project period	1/10/2021 – 31/12/2023
Coordinator	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek, the Netherlands
Beneficiaries	Centrica Storage Limited, Magyar Földgáztároló Zártkörűen Működő Részvénytársaság, NAFTA AS, Neptune Energy Hydrogen BV, Snam SpA, RAG Austria AG, Energie Beheer Nederland BV, Energieinstitut an der Johannes Kepler Universität Linz Verein, Equinor Energy AS, Shell Global Solutions International BV, Fondazione Bruno Kessler, Technische Universität Clausthal, University of Edinburgh, Forschungszentrum Jülich GmbH, Wageningen University

<http://www.hyuspre.eu/>

PROJECT AND OBJECTIVES

HyUSPRE studies 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 addresses specific technical challenges regarding storage, and conducts an economic analysis to facilitate the decision-making process for the development of a portfolio of potential field pilots. The techno-economic assessment will allow for the development of a roadmap for widespread hydrogen storage towards 2050.

NON-QUANTITATIVE OBJECTIVES

- HyUSPRE aims to conduct a study assessing the potential match of hydrogen supply

and demand sites, including the necessity of hydrogen to buffer time-varying renewable energy demands.

- The project aims to conduct a study on the potential of European hydrogen underground storage to facilitate a zero-emission energy system in 2050.

PROGRESS AND MAIN ACHIEVEMENTS

The project started on 1 October 2021.

FUTURE STEPS AND PLANS

It is expected that HyUSPRE will be executed in line with the plan for the project. The technical work has started. For the laboratory experiments, agreements have been made with industrial partners, and rock and fluid samples and data have been collected from them.

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
PRD 2022 Panel	2 – H ₂ storage and distribution
Call topic	FCH-02-1-2020: Catalyst development for improved economic viability of LOHC technology
Project total costs	EUR 2 563 322.50
Clean H ₂ max. contribution	EUR 2 563 322.50
Project period	1/1/2021 – 31/12/2023
Coordinator	Commissariat à l'énergie atomique et aux énergies alternatives, France
Beneficiaries	Kuwait Petroleum Research and Technology BV, Hydrogenious LOHC Technologies GmbH, Noordwes-Universiteit, Universidad Del País Vasco / Euskal Herriko Unibertsitatea, Evonik Operations GmbH, Friedrich-Alexander-Universität Erlangen-Nürnberg

<https://sherlohck.eu/>

PROJECT AND OBJECTIVES

Liquid organic hydrogen carriers (LOHCs) are attractive due 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 (PGM), (ii) a novel catalytic system architecture, ranging from the catalyst to the heat exchanger, to minimise the internal heat loss and to increase the space–time yield; and (iii) novel catalyst testing, system validation and demonstration in the demonstration unit (> 10 kW, > 200 hours).

PROGRESS AND MAIN ACHIEVEMENTS

The project has standardised the test protocol.

FUTURE STEPS AND PLANS

- SherLOHCK will integrate the catalyst into the thermal conductive support. The design of the first conductive support is ongoing.
- Long-term testing in continuous operation (> 200 hours) has not started yet.
- Testing of the resistance of catalysts to different poisons has not started yet.
- The modelling of the reaction kinetics for the design of new reactors has started for the dehydrogenation reaction.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
Project's own objectives	Catalyst productivity in dehydrogenation	g of H ₂ /g of catalyst/min	3	1.2		0.85	
	Degree of conversion	%	90	85		~ 100	2022
	Catalyst selectivity	%	99.8	98		~ 100	

WINNER

WORLD-CLASS INNOVATIVE NOVEL NANOSCALE OPTIMISED ELECTRODES AND ELECTROLYTES FOR ELECTROCHEMICAL REACTION



Project ID	101007165
PRD 2022 Panel	2 – H2 storage and distribution
Call topic	FCH-03-1-2020: HT proton conducting ceramic materials for highly efficient and flexible operation
Project total costs	EUR 2 931 788.75
Clean H ₂ max. contribution	EUR 2 931 788.75
Project period	1/1/2021 – 31/12/2023
Coordinator	Sintef AS, Norway
Beneficiaries	CoorsTek Membrane Sciences AS, Shell Global Solutions International BV, Aktiebolaget Sandvik Materials Technology, ENGIE, Universitet i Oslo, Danmarks Tekniske Universitet, Agencia Estatal Consejo Superior de Investigaciones Cientificas

<http://www.sintef.no/projectweb/winner/>

PROJECT AND OBJECTIVES

WINNER aims to develop an efficient and durable technology platform based on electrochemical proton-conducting ceramic (PCC) cells designed to unlock a path towards commercially viable production, extraction, purification and compression of hydrogen on a small to medium scale. WINNER uses three applications to achieve this: ammonia cracking, dehydrogenation of hydrocarbons and reversible steam electrolysis.

NON-QUANTITATIVE OBJECTIVES

WINNER aims to develop a multiscale multi-physics platform. The project is focusing on establishing a novel modelling platform combining atomistic modelling, electrochemistry, mechanical modelling, reactor modelling supported by artificial intelligence and enhanced experimental methodologies. The framework has been established and individual models are being developed. Preliminary versions of the resulting engineering models are available.

PROGRESS AND MAIN ACHIEVEMENTS

- WINNER has developed cells with state-of-the-art (SoA) materials for reversible steam electrolysis and for ammonia fuel cell to power or hydrogen.
- Process conditions have been identified and performance factors defined for each application.
- The engineering model has been developed for all three applications.

FUTURE STEPS AND PLANS

- Cells for the three applications will be further optimised. This will involve cells testing and material and architecture optimisation.
- WINNER will establish the life cycle assessment methodology, setting boundary conditions and defining relevant libraries.
- The project will establish concrete links between the various modelling scales, defining input and output parameters between each scale.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
Project's own objectives and MAWP Addendum (2018–2020)	Levelised cost of the produced hydrogen	€/kg	5	N/A		> 6 based on GAMER technology with several scaling-up assumptions	2022
	ASR of the cell	ohm.cm ² at 650 °C	< 1	1.4	⚙️	2.5	2022
Project's own objectives	Round-trip efficiency of reversible steam electrolysis	% @ 650 °C	> 75	N/A		N/A	2019
	Faradaic efficiency	%	> 95	> 95	✓	> 90	2021

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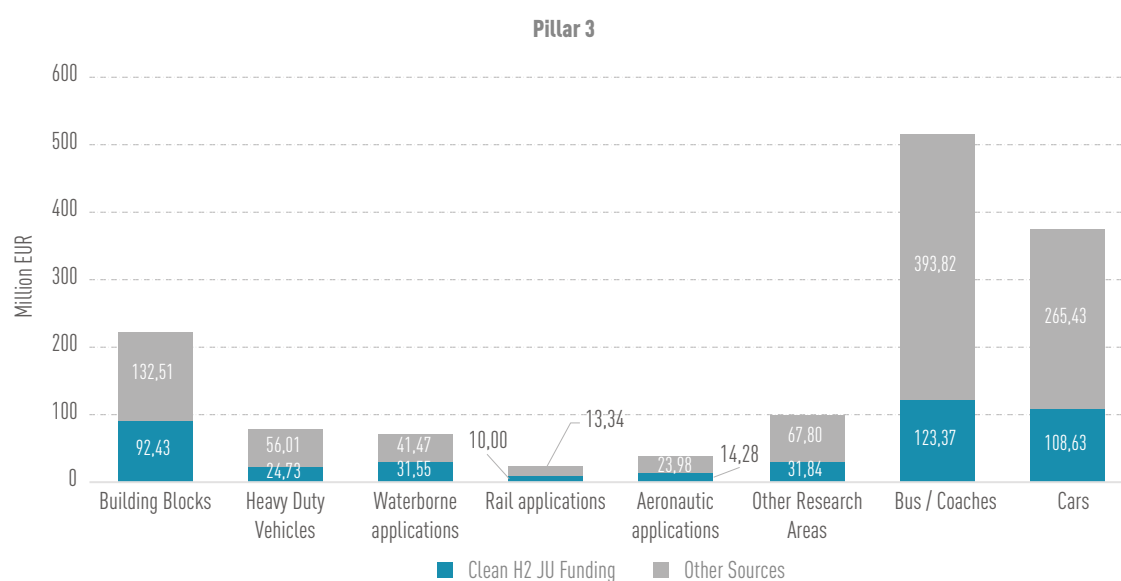
PILLAR 3 - H₂ END USES - TRANSPORT

Objectives: The Pillar 3 "Hydrogen End uses – Transport" of the Clean Hydrogen JU's SRIA aims to advance the penetration of hydrogen and fuel cell technologies in the transport sector. Several technology routes still need further improvements, especially in the context of reducing costs and increasing durability, to make them competitive with incumbent technologies:

1. Improvement of main technology building blocks that can be applied across a range of different transport applications, amongst which fuel cell stacks and hydrogen tanks;
2. Adapting fuel cell systems from other vehicles (urban buses / cars) for long distance coaches and HDV;
3. Producing components for rail freight and shunting locomotive applications;
4. Adapting fuel cell components to waterborne transport, and developing next generations based on learnings from first demonstrations;
5. Developing tanks and fuel cell technologies specifically adapted for aviation.

Budget: Following the calls between 2008 and 2020, the FCH 2 JU supported 66 projects relevant for this pillar with a total FCH 2 JU contribution of EUR 435.2 million and a contribution from partners of EUR 990.8 million. The distribution of funding over the research areas considered in this panel is shown in Figure 43.

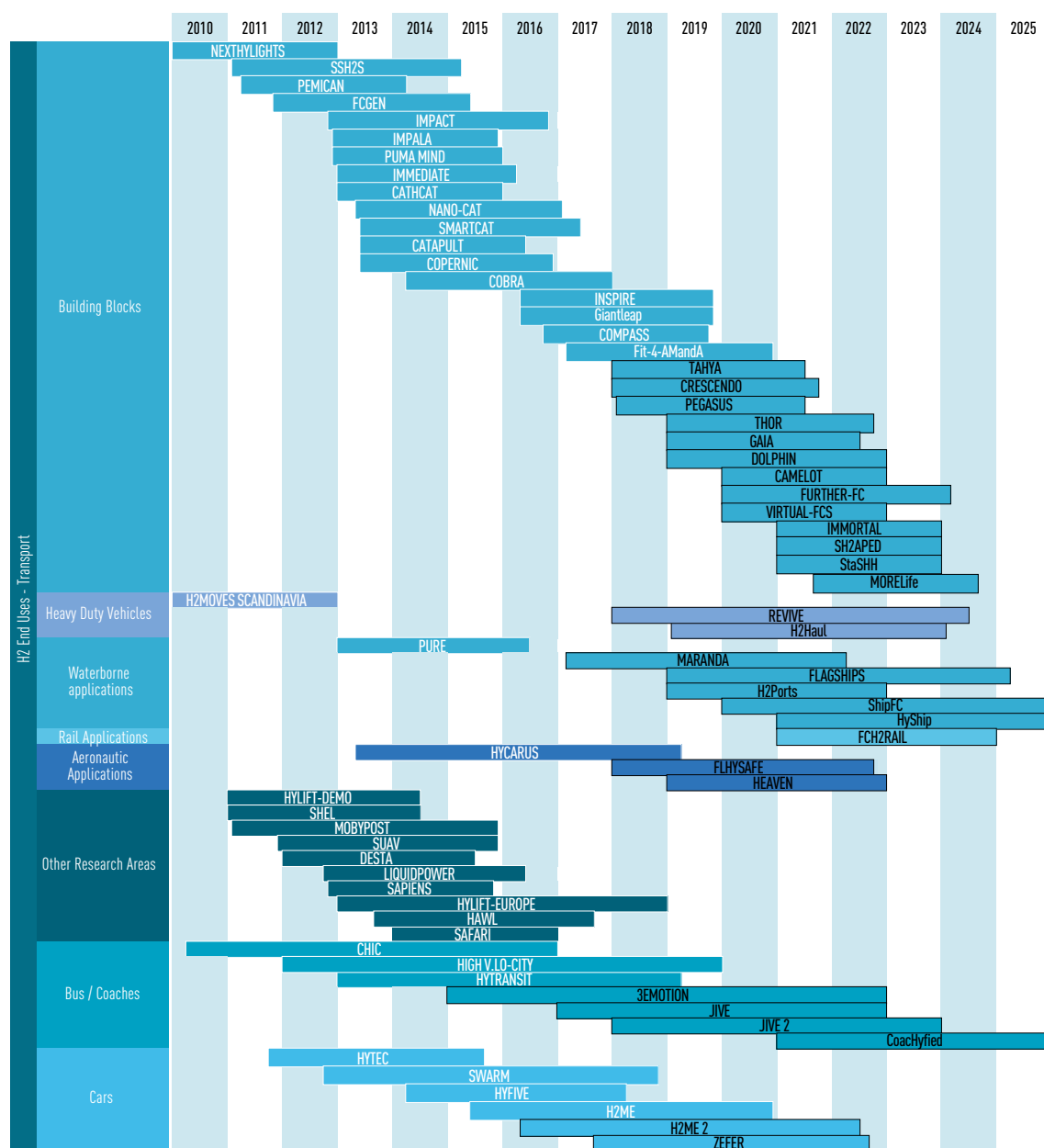
Figure 43: Funding for Pillar 3 projects from 2008 to the present.



Source: Clean Hydrogen JU

Projects: Figure 44 shows that 29 projects were on-going and/or concluded in 2021 under Pillar 3, grouped by research area. It is evident that building blocks with 13 projects since 2018 attracts a lot of attention to build capacity on the necessary components.

Figure 44: Project timelines of Pillar 3 – H₂ end uses - Transport. Projects highlighted in black were considered for the 2022 Programme Technical Assessment.



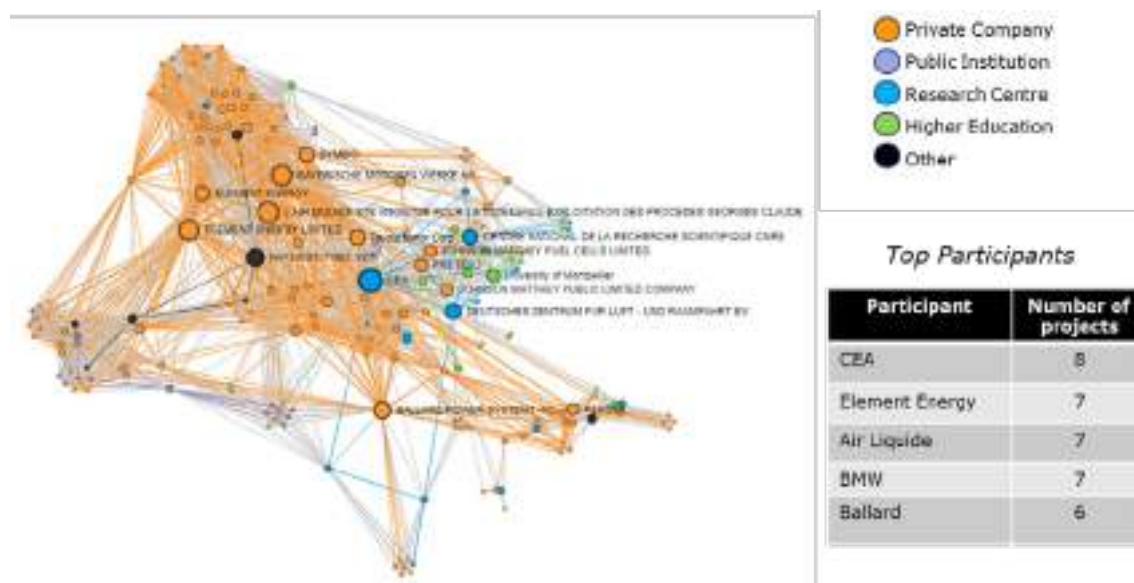
Source: Clean Hydrogen JU

Figure 45 is a plot produced using TIM. This plot shows the connections between partners present in the 29 projects reviewed within this year's Programme Review under Pillar 3¹¹⁶. 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

116. Note that the Figure 45 shows data aggregated for the 29 projects reviewed under the Pillar 3. It has not been possible to make a distinction per SRIA research area.

number of projects two partners have in common. The participants to the projects grouped under Pillar 3 often have strong links to each other). Research institutes (CEA¹¹⁷, CNRS¹¹⁸ and DLR¹¹⁹) along with the Air Liquide, Element Energy, and the fuel cell manufacturer Ballard are the key participants in this pillar (i.e. those present in the most projects).

Figure 45: TIM Plot showing the participants in the 29 projects in Pillar 3.¹²⁰



Source: TIM (JRC)

BUILDING BLOCKS

The Building Blocks Research Area includes projects on both FC stack (PEGASUS and CRESCENDO) and FC system technologies (FURTHER-FC, CAMELOT, GAIA, Virtual-FCS, IMMORTAL, DOLPHIN, MORELife and StasHH. Further, three projects on on-board vehicle hydrogen storage are assessed within this Research Area, namely TAHYA, THOR and the recently started SHA2PED.

PROJECTS ON FUEL CELL STACK TECHNOLOGIES

PEGASUS and CRESCENDO aim at developing non-PGM catalysts for PEMFC. TRL for these projects are quite low and fall in the range 2-4. The target power density for the call topic is equal to 0.42 W/cm² at 0.7 V, fed with air.

PEGASUS finished in June 2021. Its best catalyst synthesised in multi-gram batches, requiring fewer preparation steps, is nearly twice more active under O₂ than the SoA (2021), namely 9 A/g of PEGASUS catalyst vs 5.5 A/g (SoA 2021). In an MEA performance test under air, the developed PGM-free catalyst performs 420 mA/cm² @ 0.6 V (0.252 W/cm²). Similar results are reported in literature (420 mA/cm² @ 0.6V, SoA 2021), however SoA results are obtained for higher catalyst loading, namely PEGASUS 2 mg_{cat}/cm² versus 4 mg_{cat}/cm² SoA. Therefore, although the results are similar, the higher electrochemical activity of PEGASUS catalysts becomes beneficial.

117. French Alternative Energies and Atomic Energy Commission

118. Centre National de la Recherche Scientific

119. German Aerospace Centre

120. 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.

Although, obtained performance is very good (as compared with SoA) some call targets are not reached, such as (catalyst activity, durability and cost target). Especially low durability of the developed catalysts may affect project outcomes and its overall impact.

CRESCENDO, finished in September 2021, has developed a non-PGM catalyst for the PEMFC cathode reaching at small-scale (5 cm²) power density of 0.42 W/cm² at 0.6 V at H₂/air gas supply. Although at larger scales (i.e., 50 cm²) the performance dropped, this achievement is much better than SoA and can be considered as project success. The project intended also to develop non-PGM or ultra-low PGM anode catalysts with greater tolerance to CO and H₂S impurities than current low Pt loaded anodes. This target is partially achieved since the best reported results were obtained using ultra-low PGM anode catalyst. CRESCENDO uses cell hardware developed in INSPIRE.

Although scaling up of the developed technology needs more research and durability test must be performed to prove stability of catalysts, the CRESCENDO project has identified the gaps between the capabilities of current materials and industry needs, as well as ways forward to close those gaps. This can be done by comprising increased site density, active site accessibility and design features for improved mass transport.

PROJECTS ON FUEL CELL SYSTEM TECHNOLOGIES

TRL for these projects are in the range of 2-3, with the exception of DOLPHIN for which we assess targets are towards TRL 4 as it tackles short stack of 5 kW and GAIA aiming to reach TRL 5 in MEA development. StashH starts from TRL 5 targeting TRL 6-7 at the end of the project.

FURTHER-FC builds upon the PEMICAN¹²¹ project. It aims to improve gas and proton transfer near catalytic structures, and to investigate and validate performance limitations owed to coupling between electrochemical and transport issues in the cathode catalyst layer. It uses structural 3D characterizations, local operando diagnostics coupled with advanced modelling, from sub- μ m to full thickness addressing durability issues. Despite delays, it progressed with the characterisation of reference catalyst layers (common MEA with DOLPHIN project) by AFM, Raman and 3D FIB-SEM¹²² and direct numerical simulations. It also defined and validated test protocols (in exchange with ID-FAST project) and differential cell hardware.

CAMELOT project is focused on improving understanding of transport limitations in fuel cell electrodes. The project is using a combination of numerical modelling and advanced in-situ characterisation to build a scientific understanding of the limitations in state-of-the-art MEA.

The project suspended its activities in March 2021 and resumed in January 2022, due to financial problems of project partner Fuel Cell Powertrain GMBH. As it is stated in the termination report, the partner could not allocate required resources into CAMELOT project due to COVID implications. Since Fuel Cell Powertrain was leading two project's work-packages, the whole project was suspended. The project consortium agreement was renegotiated hence the two new entities are involved instead of Fuel Cell Powertrain, namely Powercell Sweden and FAST Simulation UG. The project is resumed in 2022, so there are no major achievements reported yet.

GAIA develops components (electro-catalysts, membranes, GDL¹²³ and MPL¹²⁴) and aims at improving their interfaces to minimise polarisation resistance in next generation MEAs. It delivered a BoL power density of 1.70-1.77 W/cm² at 0.6 V (1.8 W/cm² AWP2019 target), validated performance of 10 cells short stack at anode and cathode stoichiometry ratios 1.5 and 2.0 respectively, RH 50% both sides. It is a leading result, at least in terms of publicly known fuel cell performance. By reaching this high-power density without increasing platinum loading, the Pt-specific power density was reduced from 0.45 g Pt/kW (e.g. VOLUMETRIQ) to 0.25 g Pt/kW. Durability test of a full-size cell short stack) for 1,000 hours (with extrapolation to 6,000 hours) is already ongoing. Although

121. <https://cordis.europa.eu/project/id/256798/reporting>

122. Focused Ion Beam Scanning Electron Microscopy

123. Gas Diffusion Layers

124. Microporous Layer

already obtained results are promising, the conclusions from durability test will affect the overall impact of the project.

VIRTUAL-FCS develops an open source (under MIT license) software-hardware toolkit for rapidly designing and optimising PEM fuel cells/battery hybrid powertrains and systems of rail, maritime, bus, HDV¹²⁵. Despite some COVID-19 related delays, the project defined a hybrid system design and parameters for initial platform and model development¹²⁶ (i.e. battery/FC energy management, compressor, pressure regulation, air/H₂/cooling fluid subsystems, vehicle profiles – WLTC drive cycles, etc.), established a working model of a FC system and performed a critical review of existing BoP models.

IMMORTAL project develops new materials concepts for PEMFC components (electrocatalysts, membranes) by building mitigation strategies to fuel-cell-operation-induced degradation to ensure that both their activity and their stability are sustained. The potential of developed material components is utilised by introducing novel electrodes and MEA constructions to deliver step-change durability while exceeding 1.2 W/cm² at 0.675 V. Load profile tests for heavy-duty MEA performance and durability assessment will be developed, including input from real-life usage profiles from H2Haul project. The IMMORTAL project aims also on MEA performance and durability validation in full size cell short stacks using accelerated stress testing and develop a robust algorithm for lifetime prediction to 30,000 hours operation.

DOLPHIN explores an unconventional, highly innovative route towards a newly designed cell architecture featuring a Dual-Core Single Repeat Unit delivering a lightweight and compact FC stack architecture. Using mechanically strong and corrosion resistant structures redesigned for more coherent cell-internal interfaces to delay ageing and increasing system reliability compatible with automotive durability targets, projected stack production costs will be less than 20 €/kW with target power density of 1.3 W/cm² vs. SoA of 1.13 W/cm² while the 2024 target is 2.0 W/cm² at 0.66 V under nominal condition. Unfortunately, COVID restriction in access to labs and some technical difficulties with bi-polar plate manufacturing (low rib-rib pitch) have significantly limited the progress of the project. The power density achieved to date (1.15 A/cm²) is lower than project target and much lower as compared with AWP 2019 target (1.8 W/cm²). Delays and technical difficulties convince project partners to relax some “go/not go” decisions on project development paths. Although reported difficulties are well understood, they significantly hinder project progress and future impact.

Project **MORELife** matches highly innovative material developments with advanced operating condition optimisation strategies in a direct feedback-loop with test data from thorough small scale material evaluations, mechanistic modelling, and measurement data from relevant application environments. All activities are coupled with simulation and modelling to provide a deep theoretical understanding of the respective mechanisms, allow for selective MEA and stack design improvements, provide model validation from test results at an early stage, and to establish a solid basis for predicting the extended lifetimes of 30 000 h. MORELife started in September 2021.

STASHH project, started in January 2021, focuses on the development of open standards for heavy-duty fuel cells modules in terms of size, interfaces and control. designing and manufacturing of PEMFC systems for heavy-duty applications. StaSHH paramount objective is to create all the necessary conditions for fuel cells to become a competitive alternative to diesel and batteries. These conditions are affecting end users (lower total cost of ownership, reliable supply chain, fair competition), OEMs (market pooling, scalability, lower RDI) and FC materials suppliers (automation). Standardised heavy-duty FC modules have a strong potential to enable the further roll-out of fuel cell technologies in the heavy-duty sector as its competitiveness among the technology options available is expected to increase significantly due to demand pooling, scalability, automation, increased competition, supply chain reliability, tailored research, development and innovation and lower overall costs.

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

126. available at <https://github.com/Virtual-FCS/VirtualFCS>

PROJECTS ON ON-BOARD VEHICLE HYDROGEN STORAGE

Three projects form the research area on-board vehicle hydrogen storage in 2021: TAHYA, THOR and the recently started SHA2PED. TRL for these projects are in the range 4-6.

TAHYA finished in June 2021. The project result was a type 4 tank (composite wrapped vessel with a polyethylene liner) with an integrated on-tank valve. It was subjected to selected design qualification tests established in type-approval regulations, namely fire resistance, hydraulic burst and load cycle tests under various conditions, showing appropriate performance. Unfortunately, integration of the hydrogen storage system in a FCEV could not materialise because the car manufacturer stopped developing the prototype.

TAHYA obtained an outstanding gravimetric efficiency of 6.5% setting the state-of-art and meeting Clean Hydrogen JU SRIA target for on-board compressed hydrogen storage gravimetric capacity in 2024. CAPEX for TAHYA is calculated at 450 EUR/kg H₂, better than SRIA target for 2024 (500 EUR/kg H₂). TAHYA works led to an improvement of the carbon fibre winding process for tubular wrapping that reduces the amount of used carbon fibres and is in line with DoE targets (11.4 kg carbon fibers/kg H₂). Three patents related to the tank design and its manufacturing have been submitted. In addition, TAHYA results have been shared at the GTR No.13 Phase 2 contributing to the discussions on initial burst pressure requirements; probabilistic assessment of tanks performance, batch testing criteria and fire test.

THOR develops high-pressure composite hydrogen tanks (moving from TRL 4 to TRL 6) based on thermo-plastic resins. Prototype tanks are manufactured and design qualification tests, such as initial burst pressure and fire tests with embedded optical fibres, are planned for 2022. Because of the COVID related delays, the project is extended to October 2022; when the targets of reducing costs, gravimetric capacity and improved safety will be demonstrated. The final tank has the potential as a breakthrough technology for hydrogen storage, with reduced material use and costs. Following last year's recommendation, THOR took into account, for the tank design, the conclusions of previous FCH JU projects FIRECOMP, HYPACTOR and HYTRANSFER. As part of its activities THOR is investigating the process to recycle composite materials from end-of-life hydrogen tanks, preparing panels of recycled thermoplastic reinforced with carbon fibres that industry could further use.

SH2APED, started in 2021, is developing an innovative compressed hydrogen storage system of conformable size fitting into the flat space of light-duty car underbodies (TRL 4). The storage system is an assembly of nine tubular vessels fitting into a design space of 1,800 x 1,300 x 140 mm used for the battery pack on-board vehicles. The design of critical parts as the liner/boss reinforcement is completed. Simulations of the system behaviour under fire are completed as well and results have been presented in 2021. While the first prototype-vessels are available, design phases of the manifold and the assembly pack are on-going. Performance parameters and KPIs (ratio volume H₂ stored for estimated design space, cost of process for liner) are expected to improve current state-of-art for compressed hydrogen storage. Economic assessment for industrial mass manufacturing is in line with the expectations of the automotive industry; although a current challenge is the increasing cost for raw materials.

The projects in this research area have high impact, as their results are relevant for on-going standardisation efforts at ISO TC197 WG18 on *Gaseous hydrogen land vehicle fuel tanks* and TPRDs and for future updates of the global technical regulation on hydrogen fuelled vehicles safety (GTR No.13).

HEAVY DUTY VEHICLES

Demonstration activities on heavy-duty trucks, started in 2018 with the project REVIVE and enlarged in 2019 with the project H2Haul. These two projects will deploy 29 FCTs and bin-lorries at 13 sites in seven European countries.

REVIVE will demonstrate 14 refuse trucks in eight sites across Europe. Four trucks are already in operation and the remaining ones will be deployed in the coming months. The HRSs in Gothenburg and Groningen started operation in 2021 while Breda and Antwerp HRSs opened, respectively in April and May 2022. To optimise the

demonstration activities, REVIVE makes use of already existing infrastructure (for instance in Helmond, in Groningen area or in Bolzano) and of rented mobile refuelling stations. This made possible that, even with limited running hours, the four trucks deployed in the project already consumed 1 tonne of hydrogen, of which 689 kg in 2021. Those vehicles have driven 4,314 km in 2021. After some teething issues in the first vehicle deployed, trucks' downtimes are decreasing leading to a mean distance between failures in the range of 500 km.

REVIVE has synergies with other EU initiatives demonstrating fuel cell hydrogen garbage trucks such as the Interreg project HECTOR¹²⁷ (deploying seven FCTs in seven pilot sites in North-West Europe) and the LIFE project LIFE N GRABHy¹²⁸ (demonstrating garbage truck for a period of two to three weeks in 10 European cities). Both HECTOR and LIFE N GRABHy will deploy the vehicles in locations where there are already HRSs. The three projects will share lessons learned and dissemination activities as well as policy recommendations to foster the deployment of FCTs.

REVIVE is relevant for the Clean Hydrogen JU programme as it will set the basis and state-of-the-art reference for future HDV refuse truck and will demonstrate the business case of hydrogen vehicle fleets for municipal services. It is helping to improve the business case of existing public (and private Clean Hydrogen JU funded) HRS too. REVIVE is expected to improve the market readiness of FC technologies to be used in heavy-duty vehicles while contributing to develop an EU fuel cell supply chain with two European fuel cell providers and an EU fuel cell integrator participating in the project.

H2Haul will lead to the deployment of 16 trucks (including rigid and articulated vehicles up to 44 tonnes), which will be operated for at least two years in day-to-day service, in four European countries. Two existing HRSs will be upgraded and, additionally, four new HRS for refuelling of trucks will be deployed. The first HRS (in Rothenburg, Switzerland) opened in 2021, the stations in Belgium and France will open in 2022 and the station in Germany is at the planning phase.

H2Haul aims at significantly increasing the technical maturity of the heavy-duty trucks, which are developed by two major European OEMs, IVECO and VDL ETS and will use fuel cells from three suppliers. The project will be the first European project putting fuel cell electric trucks (FCTs) in the roads; its knowledge and experience will be of relevance for future projects funded under the 2022 Clean Hydrogen JU call "Large scale demonstration of European H₂ Heavy Duty Vehicle along the TEN-T corridors".

H2Haul has synergies with Interreg funded project H2Share¹²⁹. H2Share finishes in 2022, but its truck is being refurbished, by common partner VDL, and will be further demonstrated within H2Haul¹³⁰.

The projects started in 2021, STASHH, IMMORTAL and MORELIFE, will work towards standardisation of fuel cells for heavy duty vehicles and increased lifetime; both REVIVE and H2Haul provide input to STASHH. H2Haul also considers that the lack of labour skills might become a barrier for future deployments of FCTs.

The issues with certification of FCT components is also a barrier. At present homologation is granted following an individual type-approval for each vehicle, with implies redundant tests to certify components and in some cases additional tests to meet regulations of each country. The GTR No.13 Phase 2¹³¹ is developing type-approval requirements for hydrogen fuelled vehicles, including FCTs; the participation of H2Haul sharing technical knowledge and experiences at the next phase GTR No.13 is recommended.

127. Hydrogen Waste Collection Vehicles in North West Europe (HECTOR), <https://www.nweurope.eu/projects/project-search/hector-hydrogen-waste-collection-vehicles-in-north-west-europe/#tab-1>

128. <https://www.lifeandgrabhy.eu/about-project>

129. Hydrogen Solutions for Heavy-duty transport Aimed at Reduction of Emissions in North-West Europe, <https://www.nweurope.eu/projects/project-search/h2share-hydrogen-solutions-for-heavy-duty-transport/>

130. <https://www.nweurope.eu/projects/project-search/h2share-hydrogen-solutions-for-heavy-duty-transport/news/interesting-findings-during-h2-shares-closing-conference/>

131. GTR No.13 is the global technical regulation on hydrogen and fuel cell vehicles (<https://unece.org/fileadmin/DAM/trans/main/wp29/wp29wgs/wp29gen/wp29registry/ECE-TRANS-180a13e.pdf>); established in 2013. It is currently under revision (GTR N.13 Phase 2) to take into account scientific and technical progress since its creation, for instance including requirements for hydrogen trucks

On the infrastructure side, both projects are encountering trouble with permitting for the HRS. Following last year suggestion, H2Haul established collaborations with H2ME, ZEFER and JIVE (projects that have already experienced similar issues) sharing lessons learnt and organising a round table on hydrogen mobility. Experiences regarding refuelling of the H2Haul trucks and REVIVE garbage trucks fleet will be useful for identifying HRS adaptations required for trucks as well as for the development of a refuelling protocol for HDV (following and improving PRHYDE recommendations). These actions are valuable for establishing a general RCS framework for hydrogen and fuel cell heavy-duty vehicles.

Both hydrogen truck demos contain activities on carry LCA. REVIVE will perform assessment of the project performance in terms of CO₂ emissions, air pollution and noise reduction, as well as providing a comparison between diesel, electric and FCH refuse trucks. It will carry out well-to-wheel (WTW) assessments with using project data and results specific to each demonstration site, taking into account their respective hydrogen supply chain. Moreover, REVIVE will explore the feasibility of an integrated hydrogen production solution from waste. H2Haul will also perform a WTW analysis and a life cycle cost evaluation.

REVIVE and H2Haul experiences will serve to address other cross cutting issues such as vehicles and HRS safety, training of drivers and maintenance workers, risk assessments and customer acceptance. These two projects are setting the basis for larger demonstration initiatives, as the future flagship project under the 2022 AWP call topic "Large scale demonstration of European H2 Heavy-Duty Vehicle along the TEN-T corridors" aimed at deploying a minimum of 150 trucks, from at least 3 original equipment manufacturers and six operators. Truck demonstration projects are increasing their visibility, last year the projects participated to the Digital Roundtable for Hydrogen Mobility involving technical experts, representatives from government and EP members. Moreover, last year H2Haul won the Hydrogen Transport Award at the first edition of the World Hydrogen Awards organised by the Sustainable Energy Council. In addition, to several high-level conferences, H2Haul took part in a technical table on the strategic plan for a hydrogen valley at Tuscan coast in Italy and published an article on Open Access Government¹³².

WATERBORNE APPLICATIONS

MARANDA objective was to develop an emission-free hydrogen-fuelled 165 kW (2 x 82.5 kW AC) PEMFC based hybrid powertrain system for marine applications and demonstrate it on board the arctic research vessel Aranda. In 2021, the validation test of the three assembled fuel cells was completed. Permit for their installation was not granted and MARANDA will be concluded with final durability tests carried out onshore at an industrial site. The FCS durability is estimated at 20,000 hours as no degradation has been observed. The system electrical efficiency (LHV) resulted at 42% while the target was 48% at BoL, however there are uncertainties with the results and improved measurements are on-going in 2022.

ShipFC will develop a 2 MW ammonia SOFC and will operate a retrofitted offshore vessel for at least 3,000 hours per year. The fuel cells are being scaled up and are going through testing in laboratory. The tests of the full size 2 MW system are planned for 2023. The vessel will be the first one powered with an ammonia and using SOFC in the range of MW.

HyShip, started in January 2021, is the first Clean Hydrogen JU project on LH₂ fuelled vessels, demonstrating one vessel powered three-MW PEM fuel cells. It will bring forward the state-of-art, which is currently given by a 400 kW fuel cell and LH₂ propulsion in the Norwegian "HyDRA" ferry¹³³. It will benefit from the knowledge and experience of partners in common with HySeas III (Horizon 2020)¹³⁴ deploying a passenger and car ferry in the Scottish Orkney Islands.

132. <https://www.openaccessgovernment.org/heavy-duty-transport/107132/>

133. <https://fuelcellworks.com/news/norse-group-announces-launch-of-mf-hydra-worlds-first-lh2-driven-ferry-boat/>, <https://www.offshore-energy.biz/ballard-fuel-cells-for-worlds-largest-lh2-powered-ferry/> and http://elizabethqueenseaswinn.com/HISTORY/LH2-Ships_Ferries_Yachts_Hydrogen_Projects/MF_Hydra_Norled_Car_Ferry_Norway_Liquefied_Hydrogen_Liquide.html

134. <https://www.hyseas3.eu/the-project/>

H2Ports aims to demonstrate hydrogen as an alternative fuel in maritime ports. It will carry out pilot tests in the Port of Valencia, under real operation conditions, for a hydrogen-powered reach stacker in a port container terminal, a fuel cell yard tractor for container transport and ro-ro loading/unloading operations, and a mobile hydrogen supply station. Both the reach stacker and the yard tractor will be first of their kind using fuel cells to provide respectively 90 kW and 70 kW power.

RAIL APPLICATIONS

FCH2Rail, started in January 2021, is developing a hybrid, bi-modal drive system for trains powered by electrical supply from the overhead line with and by a hybrid pack consisting of fuel cells and batteries when no catenary line is available. The fuel cell hybrid power pack will be installed in the demonstrator train (an electric commuter train that is being now refurbished). Currently there are no available specific regulations for hydrogen fuelled trains and the project is relying on existing regulations from road vehicles for homologating the hydrogen storage system and the fuel cells. FCH2Rail is participating to ongoing standardization at IEC groups working on IEC63341 - Fuel cells in rail applications and it is recommended that follows the developments of IEC TC 9 on PNW 9-2697 ED1: Railway applications – Rolling stock – Fuel cell systems for propulsion - Part 2: Hydrogen storage systems.

AVIATION APPLICATIONS

FLHYSAFE draws on experience from HYCARUS to demonstrate a cost efficient modular fuel cell system that can replace the most critical safety systems used as an emergency power unit aboard a commercial airplane. It completed the design for fuel cell integration into airborne applications. FC short stack testing (using oxygen instead of air) as well as start/stop cycle stack degradation analysis. The experiments show that 466 starts/stop cycles resulted in 0.05 W/cycle degradation rate. No premature degradation due to operating at O₂ instead of air is noticed.

HEAVEN project aims to equip an existing small 4-place aircraft with a FC based powertrain, hence increase of aeronautic FC-based powertrain TRL from 3 to 6. This requires further actions, namely: an optimisation of balance-of-plant components using cryogenic hydrogen storage technology without employing a battery energy buffer; and implementation of BoP into FC based powertrain.

BUSES AND COACHES

3EMOTION, **JIVE** and **JIVE 2** are ongoing and progressing, although with delays with respect to the original planning. 3EMOTION has deployed all 29 buses: 10 buses in London, 6 in Rotterdam and the South Holland province, 7 in Versailles, 3 in Pau and 3 in Aalborg. The project has demonstrated the operability of buses from four different manufacturers with two different fuel cells systems. The buses are largely meeting their targets on hydrogen consumption and availability. In 2021, the 3EMotion FC buses have collectively covered 741,113 km with 64.16 tonnes of hydrogen tanked.

Combined JIVE and JIVE 2 are deploying over 300 fuel cell buses in 22 cities across Europe, the largest deployment in Europe to date (Figure 46). The local fleets range from 5 to 50 FCBs, typically 10 to 20. As of 2021, JIVE has ordered all the 142 planned buses and 121 are in operation, while JIVE 2 has ordered all the 156 buses originally planned, has 98 buses in operation and expects to have the committed fleet delivered by the end of March 2023.

Figure 46: Fuel cell bus demonstration sites in Europe.



Source: <https://www.fuelcellbuses.eu/>

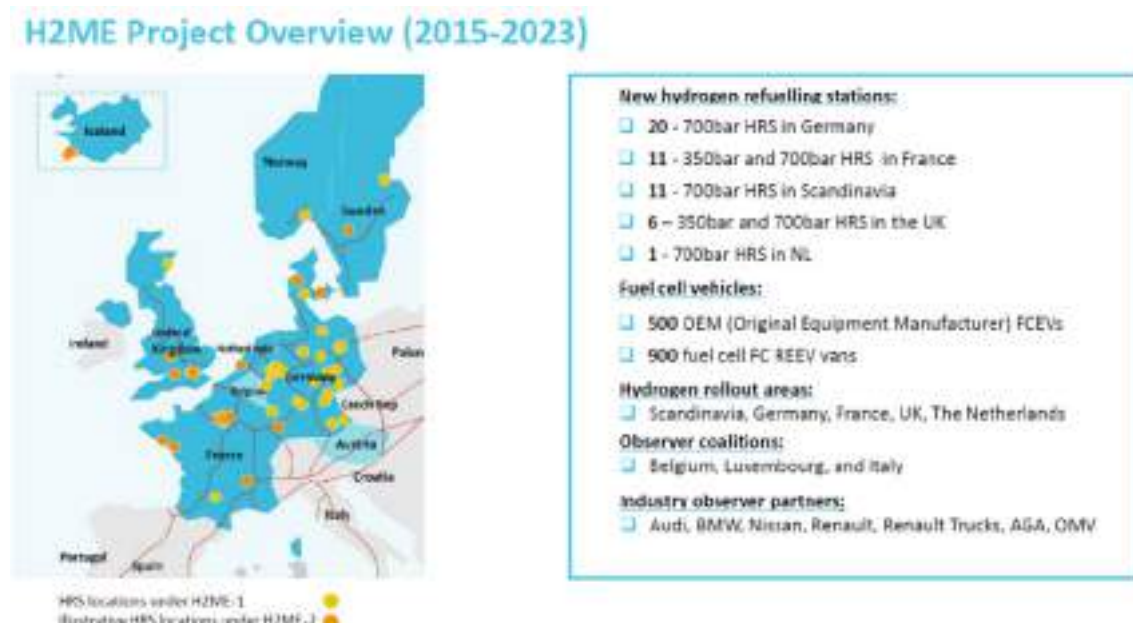
In 2021, there were 247 Clean Hydrogen JU buses in operation in 8 cities. From the bus demonstration projects that were reporting in TRUST between 2016 and 2021, a total distance of over 11.4 million km was accumulated, with almost 2.5 million km accumulated in 2021 alone. In the last five years, over 793 tonnes of hydrogen have been consumed, of which 24% in 2021. The fuel consumption of FCB has improved in the last years. In 2021, the average fuel consumption was 8.3 kg hydrogen per 100 km while the minimum fuel consumption reported was 5.6 kg H₂/100 km, meeting the 2020 MAWP target (values range from 8 to 10.2 kg H₂/100 km) and on track to meet the 2024 MAWP target (average 7.5 kg H₂/100 km).

A major advantage for FCBs is the longer distance range they can achieve in comparison to battery electric buses; the new Clean Hydrogen JU project (2020 call). **CoachHyfied** project, which started in January 2021, is aiming to demonstrate coaches with fuel cell powertrains in regional and long-distance passenger transport.

CARS

The H2ME initiative (H2ME and H2ME2 projects) is the largest European deployment to date for hydrogen mobility, planning to deploy more than 1400 vehicles in 8 countries and 49 HRS in 6 countries (see Figure 47).

Figure 47: Overview of the H2ME initiative.



Source: H2ME

Project H2ME has deployed 311 vehicles and 29 new HRSs in Germany, Scandinavia, France and the United Kingdom. Austria, Belgium and the Netherlands were participating as observers. H2ME2 has already deployed 501 from the more than thousand vehicles planned. FCEVs from five OEMs and 12 H2ME2 hydrogen refuelling stations (out of 20) were put into operation. The commissioning of new HRS has been impacted by the COVID-19 pandemic and by the lack of experience at local level for reviewing and approving permits authorization. Most of the HRS to be commissioned have obtained the permit and all of them should be in operation by the end of 2022.

Project ZEFER started in 2017 with the objective of demonstrating viable business cases for captive fleets of FCEVs (taxi, private hire and police services) and is expected to be concluded in 2022. Fleet vehicles are subjected to high mileages and typically refuel at a centralized fuelling station at the depot, creating a favourable business case for a HRS. The 180 FCEVs planned are already in operation (60 in Paris, 60 in London and 60 in Copenhagen). The cars in Paris have been added to the already existing 74 FCEVs HYPE taxi fleet, while in London 50 are private hire vehicles by Green Tomato and 10 are police operation vehicles. Initially, ZEFER project aimed to deploy 60 FCEVs in Brussels but permitting issues to operate the taxi fleet delayed the deployment of vehicles in Brussels for 3 years. This led to a significant delay in the project. A suitable alternative was found in Copenhagen, which allowed the quick deployment of vehicles into taxi fleets in November 2021 and allowed the project to meet all the requirements.¹³⁵

The average 2021 fuel consumption of 1.12 kilogramme (kg) per 100 km is lower than the MAWP 2020 target (1.15 kg per 100 km) and on track to achieve the 2024 target of 1.1 kg per 100 km. The average vehicle availability reached 99% in 2020, which means that the expected MAWP 2020 targets for availability (98%) and fuel cell system durability (6,000 hours) have also been accomplished. FCEVs have been demonstrated as reliable, with equal driving ranges to conventional light duty vehicles.

135. <https://zefer.eu/uncategorised/toyota-and-drivr-put-100-hydrogen-taxi-on-the-roads-in-copenhagen/>

3EMOTION

ENVIRONMENTALLY FRIENDLY, EFFICIENT ELECTRIC MOTION



Project ID	633174
PRD 2022 Panel	3 – H2 end uses: Transport
Call topic	SP1-JTI-FCH.2013.1.1: Large-scale demonstration of road vehicles and refuelling infrastructure VI
Project total costs	EUR 38 181 930.72
Clean H ₂ max. contribution	EUR 14 999 983
Project period	1/1/2015 – 31/12/2022
Coordinator	Van Hool NV, Belgium
Beneficiaries	Aalborg Kommune, Acetilene & Gastecnici di Bagnoli Maria & C. SAS, Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile, Air Liquide Advanced Business, Air Liquide Advanced Technologies SA, Autocars Dominique, Azienda per la mobilità del Comune di Roma SpA, B.E. green, Centro Interuniversitario di Ricerca per lo Sviluppo Sostenibile, Commissariat à l'énergie atomique et aux énergies alternatives, Communauté urbaine de Cherbourg, Commune de Cherbourg-en-Cotentin, Compagnia Trasporti Laziali, Connexxion Openbaar Vervoer NV, Connexxion Vloot BV, Dantherm Power AS, Fit Consulting SRL, London Bus Services Limited, Provincie Zuid-Holland, Regione Lazio, Region Nordjylland (North Denmark Region), Rotterdamse Elektrische Tram NV, Services automobiles de la vallée de Chevreuse SAS, Syndicat mixte des transports urbains de Pau Porte des Pyrénées, Università degli Studi di Roma 'La Sapienza, Vlaamse Vervoersmaatschappij De Lijn, WaterstofNet VZW

<http://www.3emotion.eu/>

PROJECT AND OBJECTIVES

The 3Emotion project aims to operate 29 fuel cell buses (FCBs) in five leading European cities – London, Pau, Versailles, Rotterdam (with intercity links throughout the province of South Holland) and Aalborg – and develop three new hydrogen-refuelling stations (HRSs).

Objectives:

- lower H₂ consumption to < 9 kg/100 km;
- integrate the latest drivetrain, fuel cell and battery technology to lower the total cost of ownership and increase FCBs' lifetimes;
- ensure FCB availability of > 90 %;
- increase warranties (> 15 000 hours and improved delivery times of the key components);
- reduce bus investment costs to 850 000 k€ for a 13 m bus.

PROGRESS AND MAIN ACHIEVEMENTS

- All 29 FCBs and all three HRSs are in operation.
- The project has implemented three bus original equipment manufacturers with two different fuel cells at the 'set' bus price of the initial call, operating in different EU sites.
- The buses are largely meeting their targets on H₂ consumption, average consumption and availability.

QUANTITATIVE TARGETS AND STATUS

Target Source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
	Lower H ₂ consumption for FCBs to < 9 kg/100 km	kg/100 km	9	Average of 8 kg/100 km	✓
Project's own objectives	Ensure FCB availability of > 90 %	%	90	≤ 80 %	⚙️
	Increase warranties (> 15 000 hours)	hours	15 000	15 000	✓
	Investment cost of <850 000K € for a 13 m bus	€	850 000	850 000	✓

FUTURE STEPS AND PLANS

- The project will be finalised by 30 December 2022, with the aim of all buses operating at all locations.
- 3Emotion will meet the expectation of having higher capacities at the HRSs. After COVID-19, in the final year of the project, the operation of the buses will be resumed, and full operation of HRSs can be achieved.
- The project will perform the data monitoring and gathering of operational and performance indicators for the FCBs and the HRSs.



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CAMELOT

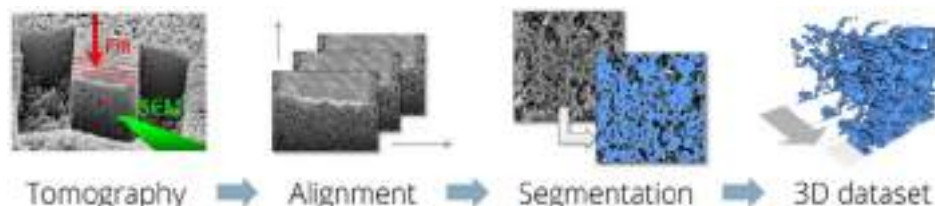
UNDERSTANDING CHARGE, MASS AND HEAT TRANSFER IN FUEL CELLS FOR TRANSPORT APPLICATIONS

Project ID	875155
PRD 2022 Panel	3 – H2 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
Clean H ₂ max. contribution	EUR 2 295 783.50
Project period	1/1/2020 – 31/12/2022
Coordinator	Sintef AS, Norway
Beneficiaries	Fuel Cell Powertrain GmbH, Johnson Matthey Fuel Cells Limited, Pretexo, Bayerische Motoren Werke Aktiengesellschaft, Albert-Ludwigs-Universität Freiburg, Technische Universität Chemnitz, Johnson Matthey plc

<https://camelot-fuelcell.eu>

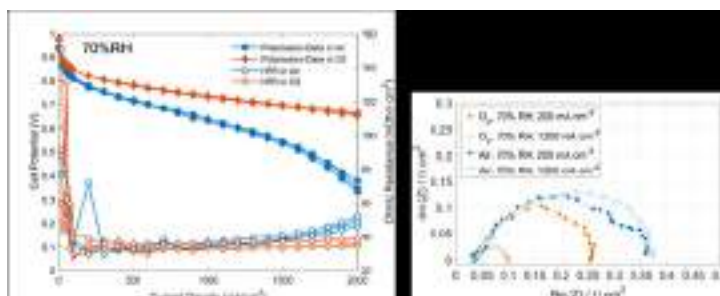
PROJECT AND OBJECTIVES

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



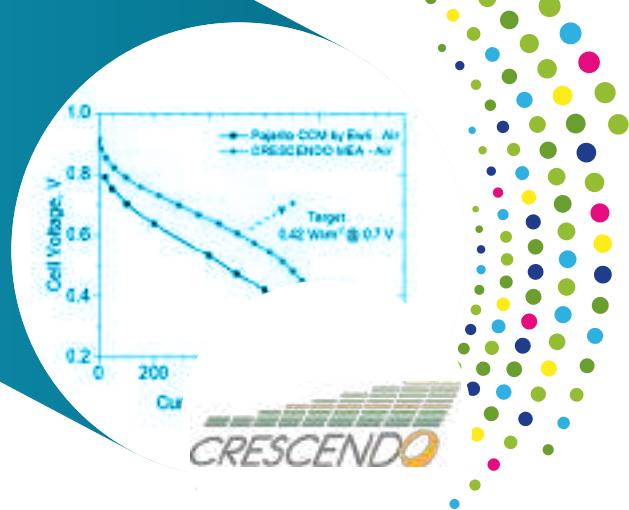
QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Membrane thickness	μm	< 10	



CRESCENDO

CRITICAL RAW MATERIAL ELECTROCATALYSTS REPLACEMENT ENABLING DESIGNED POST-2020 PEMFC



Project ID	779366
PRD 2022 Panel	3 – H2 end uses: Transport
Call topic	FCH-01-2-2017: Towards next generation of PEMFC: Non-PGM catalysts
Project total costs	EUR 2 739 602.5
Clean H ₂ max. contribution	EUR 2 739 602.5
Project period	1/1/2018 – 30/6/2021
Coordinator	Centre national de la recherche scientifique, France
Beneficiaries	Université de Montpellier, Johnson Matthey Fuel Cells Limited, Preteco, Bayerische Motoren Werke Aktiengesellschaft, Johnson Matthey plc, Technische Universität Berlin, Commissariat à l'énergie atomique et aux énergies alternatives, Imperial College of Science Technology and Medicine, Università degli Studi di Padova

<http://www.crescendo-fuelcell.eu/>

PROJECT AND OBJECTIVES

CRESCENDO reached the power density target of 0.42 W/cm² with an air feed with a platinum-group-metal (PGM)-free cathode at 0.6 V, in small-area hardware in optimised operation conditions, in the final weeks of the project. This major achievement is on a par with the highest-performing PGM-free catalysts internationally. The project has identified the gaps between the capabilities of current materials and catalyst layers, and industry needs, and ways to close that gap, comprising increased site density and active-site accessibility, and design features for improved mass transport.

PROGRESS AND MAIN ACHIEVEMENTS

- The power density target was achieved.
- CRESCENDO was strongly affected by COVID-19 owing to university laboratory closures and limitations to on-site working. This meant that the power density target was achieved significantly later than planned, and that activities for scale-up and industrial validation had to be carried out on catalysts that had inferior activity compared with the final project material.

FUTURE STEPS AND PLANS

- The project finished in 2021.
- Innovation Radar analysed and uploaded the results to enable further exploitation; see the web page 'Novel stabilizers and stabilization techniques for non-PGM catalysts for PEMFCs' (<https://www.innoradar.eu/innovation/37272>).

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
	Power density	W/cm ²	0.42 (at 0.7 V)	0.42 (at 0.6 V)	✓	0.45 (at 0.6 V)	2020
AWP 2018	Durability at 1.5 A/cm ²	hours	1 000	Not achieved	⚙️	No durability data available at 1.5 A/cm ²	N/A
	Current density at 0.9 V (iR-free)	mA/cm ²	44	41.3	⚙️	28.5	2020

DOLPHIN

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

Project ID	826204
PRD 2022 Panel	3 – H2 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
Clean H ₂ max. contribution	EUR 2 962 681.25
Project period	1/1/2019 – 31/12/2022
Coordinator	Commissariat à l'énergie atomique et aux énergies alternatives, France
Beneficiaries	Chemours France SAS, Chemours Belgium, Chemours International Operations SARL, Hexcel Composites GmbH & Co KG, DMG MORI Additive GmbH, Symbio, Faurecia Systemes D'echappement SAS, Hexel Reinforcements SAS, Hexcel Composites Ltd, Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg, University of Manchester

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

PROJECT AND OBJECTIVES

The overall aim of the project is to validate disruptive technologies for 100 kW lightweight and compact fuel cell stack designs, reaching outstanding (specific and volumic) power density, while simultaneously featuring enhanced durability (under automotive application conditions) compared with state-of-the-art (SoA) stacks, and being compatible with large-scale/mass production of full-power stacks. Validation of the DOLPHIN technologies will be supported by the design and fabrication of an automotive stack of 5 kW, representative of 100 kW power stacks.

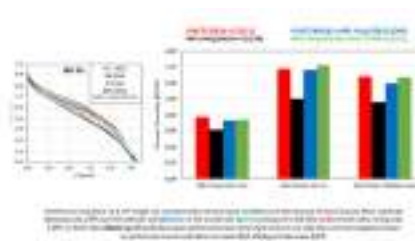
PROGRESS AND MAIN ACHIEVEMENTS

- Owing to the reduction in rib-channel dimensions, an increase in performance has been achieved.

- Manufacturing methods (printing, laser milling, additive manufacturing, etc.) have been developed to produce flow fields with thin dimensions on metallic and composite thin sheets.

FUTURE STEPS AND PLANS

- The selection of the most promising components/technologies for short stacks and 5 kW stacks is ongoing (2022–2023). Some materials have already been selected.
- The project will undertake performance and durability tests of the 5 kW stack (or 2–3 kW if necessary) (2023). Relevant test protocols have been defined.
- The experimental validation of the different routes of the project to increase performance and durability is ongoing. The life cycle analysis (LCA) will also be one of the parameters to take into account.



QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
	Weight-specific power density	kW/kg	4		3.4	
	Volume-specific power density	kW/l	5		4.1	
AWP 2018	Surface power density	W/cm²	2		1.13	2017 (by Auto-Stack CORE)
	Durability	hours	6 000		3 500	
	Stack cost	€/kW	20		36.8	

FCH₂RAIL

FUEL CELL HYBRID POWERPACK FOR RAIL APPLICATIONS



Project ID	826204
PRD 2022 Panel	3 – H2 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 13 341 609.93
Clean H ₂ max. contribution	EUR 9 999 999.12
Project period	1/1/2021 – 31/12/2024
Coordinator	Deutsches Zentrum für Luft- und Raumfahrt EV, Germany
Beneficiaries	CAF Digital & Design Solutions SA, Faiveley Transport Leipzig GmbH & Co. KG, Renfe Viajeros SA, Centro de Ensayos y Analisis Cetest SL, CAF Turnkey & Engineering SL, CAF Power & Automation SL, Centro Nacional de Experimentación de Tecnologías de Hidrógeno y Pilas de Combustible Consorcio, Stemmann-Technik GmbH, Renfe Operadora, Toyota Motor Europe NV, Construcciones y Auxiliar de Ferrocarriles Investigación y Desarrollo SL, Infraestruturas de Portugal SA, Construcciones y Auxiliar de Ferrocarriles SA, Administrador de Infraestructuras Ferroviarias

<http://www.fch2rail.eu/>

PROJECT AND OBJECTIVES

The project consortium is developing and testing a new train prototype. At the heart of the project is a hybrid, bimodal drive system that combines the advantages of an electrical power supply from the overhead line with a hybrid power pack consisting of fuel cells and batteries. This system allows for 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 analysis of gaps in the normative framework.

PROGRESS AND MAIN ACHIEVEMENTS

The project is ongoing. The focus is on case data analysis and developing the methodology.

FUTURE STEPS AND PLANS

- Testing of the fuel cell hybrid power pack (FCHPP) traction system components on the test bench started in 2022 and is expected to end in late autumn 2022. During testing, the system characteristics and the controls will be optimised.
- The integration of the FCHPP traction system into the demonstrator train has started with the integration concept, schematics and drawings. The physical integration of FCHPP components in the demonstrator train will be performed soon.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	System lifetime/durability	N/A	N/A	
	Hydrogen and electricity consumption	To be configured	To be configured	

FLAGSHIPS

CLEAN WATERBORNE TRANSPORT IN EUROPE



Project ID	826215
PRD 2022 Panel	3 – H2 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
Clean H ₂ max. contribution	EUR 4 999 978.75
Project period	1/1/2019 – 31/3/2025
Coordinator	Teknologian tutkimuskeskus VTT Oy, Finland
Beneficiaries	Sogestran, Sogestion, Future Proof Shipping BV, LMG Marin France, LMG Marin AS, Norled AS, Seam AS, Maritime Cleantech, Persee, Compagnie Fluviale de Transport, Ballard Power Systems Europe AS, ABB Oy, Kongsberg Maritime AS

<http://www.flagships.eu/>

PROJECT AND OBJECTIVES

Two commercially operated hydrogen fuel cell vessels will be demonstrated, one in France (Paris) and one in the Netherlands (Rotterdam). The Paris demonstrator is a self-propelled barge operating as a goods transport vessel in the city centre; the Rotterdam demonstrator is a container vessel transporting goods between Rotterdam and Duisburg. The Paris demonstrator vessel is built and is en route to France where H₂ fuel cell systems will be installed. The Rotterdam demonstrator entered the project at the end of 2021, and the design work for that vessel has begun.

NON-QUANTITATIVE OBJECTIVES

- The project aims to develop and demonstrate bunkering technologies based on swapping gaseous hydrogen fuel containers.
- Procedures for hydrogen bunkering are being developed and will be demonstrated in 2022.

PROGRESS AND MAIN ACHIEVEMENTS

- The FCwave fuel cell module that was designed is ready and the type approval process has started.
- The Zulu vessel (Paris demonstrator) design is ready and has been built at the site.

FUTURE STEPS AND PLANS

- The process of gaining approval for the Zulu vessel is ongoing, involving Bureau Veritas and local authorities. Approval is expected to be granted in 2022.
- The project will demonstrate the Zulu vessel in commercial operation. Operations are expected to begin in September 2022.
- FLAGSHIPS will finalise the design and retrofitting of the FPS WAAL vessel. Work started at the beginning of 2022 after an amendment was accepted. It is expected to be finalised in 2022–2023.



QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	PEMFC system availability	%	95	✓
	Complete fuel cell and H ₂ system cost	€/kW	4 000	⚙️
MAWP (2014–2020)	PEMFC system lifetime	hours	25 000	

FLHYSAFE

FUEL CELL HYDROGEN SYSTEM FOR AIRCRAFT EMERGENCY OPERATION



Project ID	779576
PRD 2022 Panel	3 – H2 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
Clean H ₂ max. contribution	EUR 5 063 023
Project period	1/1/2018 – 30/9/2022
Coordinator	Safran Power Units, France
Beneficiaries	Safran Aerotechnics, Instituto Nacional De Técnica Aeroespacial 'Esteban Terradas', ARTTIC, Universität Ulm, Deutsches Zentrum für Luft- und Raumfahrt EV, Commissariat à l'énergie atomique et aux énergies alternatives

<http://www.flhysafe.eu/>

PROJECT AND OBJECTIVES

In the shift towards 'More Electric Aircraft' (MEA), fuel cell systems are considered one of the best options for efficient power generation. The main objective of FLHYSAFE is to demonstrate that a cost-efficient modular fuel cell system can replace the most critical safety systems and be used as an emergency power unit aboard a commercial aeroplane, providing enhanced safety functionalities. In addition, the project has the ambition of virtually demonstrating that the system can be integrated, respecting both installation volumes and maintenance constraints, using current aircraft designs.

NON-QUANTITATIVE OBJECTIVES

The project aims to prepare a plan of the environmental tests to achieve the airworthiness qualification. Instituto Nacional de Técnica Aeroespacial has initiated the regulations study, and the test plan is in progress.

PROGRESS AND MAIN ACHIEVEMENTS

- The short stack was validated by H₂/O₂ tests.
- A critical design review of the low-temperature module for the fuel cell system was performed.
- A demonstrator critical design review (for major subsystems) was performed.

FUTURE STEPS AND PLANS

- The assembly and testing of the low-temperature fuel cell module are ongoing.
- The assembly and testing of the FLHYSAFE demonstrator are ongoing.
- The total cost of ownership study is ongoing.
- The virtual reality study is ongoing.



QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objectives	EPU weight (taking into account thermal management, electrical and power management, but excluding hydrogen storage)	kg	150	220	⚙️
	System power density	W/kg	100	78	✓
	Nominal continuous electrical power	kW	18.1	18.1	✓

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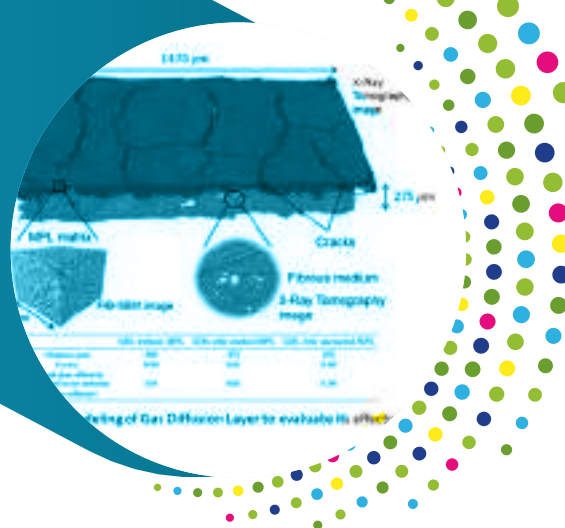
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FURTHER-FC

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



Project ID	875025
PRD 2022 Panel	3 – H2 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
Clean H ₂ max. contribution	EUR 2 199 567.35
Project period	1/1/2020 – 29/2/2024
Coordinator	Commissariat à l'énergie atomique et aux énergies alternatives, France
Beneficiaries	Chemours France SAS, The Chemours Company FC, LLC, Université De Montpellier, Hochschule Esslingen, Toyota Motor Europe NV, École nationale supérieure de chimie de Montpellier, University of Calgary, Institut national polytechnique de Toulouse, Deutsches Zentrum für Luft- und Raumfahrt EV, Imperial College of Science Technology and Medicine, Paul Scherrer Institut, Centre national de la recherche scientifique (CNRS)

<https://further-fc.eu/>

PROJECT AND OBJECTIVES

FURTHER-FC proposes complete experimental and modelling coupled platforms 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 (different ionomer-to-carbon ratio, thickness, etc.) have been produced, models of the CCLs are progressing based on their structural characterisation, and the first effective properties have been derived.

PROGRESS AND MAIN ACHIEVEMENTS

- Progress has been made on the characterisation of the CCLs (atomic force microscopy, Raman, three-dimensional focused ion beam scanning electron microscopy, etc.).

- Progress has been made on the modelling of the CCLs.
- The definition and validation of test protocols allows for reliable comparison between the partners.

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 definition of the most performance-limiting mechanisms is ongoing.
- The upscaling of the models as necessary has not started yet.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
	Volumetric power density	kW/l	9.3		4.1	
	Weight power density	kW/kg	4		3.4	
	Surface power density	W/cm ²	1.8		1.13	
MAWP (2014–2020)	Cost	€/kW	20		36.8	2017 (by Auto-Stack Core)
	Durability	hours	6 000		3 500	
	Total Pt loading	mg/cm ²	0.144		0.4	
	Total Pt loading	g/kW	0.08		0.35	
	Pt efficiency	A/mg	15		4.5	

GAIA

NEXT GENERATION AUTOMOTIVE MEMBRANE ELECTRODE ASSEMBLIES



Project ID	826097
PRD 2022 Panel	3 – H2 end uses: Transport
Call topic	FCH-01-5-2018: Next generation automotive MEA development
Project total costs	EUR 4 493 025
Clean H ₂ max. contribution	EUR 4 493 025
Project period	1/1/2019 – 30/6/2022
Coordinator	Centre national de la recherche scientifique, France
Beneficiaries	Dyneon GmbH, Université de Montpellier, Johnson Matthey Fuel Cells Limited, Pretexco, Freudenberg Performance Materials SE & Co KG, 3M Deutschland GmbH, Elmarco SRO, Bayerische Motoren Werke Aktiengesellschaft, Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg, Johnson Matthey plc, Technische Universität München, Technische Universität Berlin

<http://www.gaia-fuelcell.eu/>

PROJECT AND OBJECTIVES

GAIA aims to develop high-performance automotive membrane electrode assemblies (MEAs) capable of achieving a 6 000-hour lifetime. By month 38, GAIA had validated its stack hardware and optimised its testing protocols, and developed new carbon support, catalyst, ionomer, membrane, reinforcement, gas diffusion and microporous layer components. The project has reached its first five milestones, which include achieving a leading power density of 1.8 W/cm² at 0.6 V in full-size cell short stacks. Techno-economic evaluation will assess how the GAIA MEA cost is positioned with respect to the very ambitious 6 €/kW MEA cost target.

NON-QUANTITATIVE OBJECTIVES

- The project aimed to perform outreach through videos on catalyst preparation and characterisation by rotating disk electrode and catalyst integration into MEAs and testing/diagnostics, prepared by Technische Universität Berlin and Technische Universität München.

- It aimed to disseminate the results through articles in international journals; four articles have been published and one article has been accepted for publication.
- It also aimed to communicate results through the publication of three newsletters on its website.

PROGRESS AND MAIN ACHIEVEMENTS

- The project developed MEAs that provide 1.8 W/cm² at 0.6 V.

FUTURE STEPS AND PLANS

- GAIA will complete the performance and durability testing with the Gen4 short stack. Testing commenced in 2022.
- The project will complete the techno-economic analysis, which will provide a €/kW metric for the GAIA MEAs.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
	Power density at 0.6 V	W/cm ²	1.8	1.8	✓	No public data at 3 A/cm ² under call conditions	N/A
AWP 2019	Durability (voltage decay rate)	%	< 10 % after 6 000 hours of operation	Test is running	⚙️	10 % after 500 hours of automotive drive cycle testing	2019
	MEA cost	€/kW	6	N/A	⚙️	13 (estimated)	2017

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H2HAUL

HYDROGEN FUEL CELL TRUCKS FOR HEAVY-DUTY, ZERO EMISSION LOGISTICS

Project ID	826236
PRD 2022 Panel	3 – H2 end uses: Transport
Call topic	FCH-01-1-2018: Large scale demonstration of H2 fuelled HD trucks with high capacity hydrogen refuelling stations (HRS)
Project total costs	EUR 28 137 376.80
Clean H ₂ max. contribution	EUR 12 000 000
Project period	1/2/2019 – 31/1/2024
Coordinator	Element Energy Limited, United Kingdom
Beneficiaries	DATS 24, Plastic Omnium New Energies Wels GmbH, Element Energy, H2 Energy AG, Air Liquide France Industrie, VDL Enabling Transport Solutions BV, VDL Special Vehicles BV, Eoly, FPT Motorenforschung AG, Hydrogenics GmbH, IRU Projects ASBL, FPT Industrial SpA, Air Liquide Advanced Technologies SA, Sphera Solutions GmbH, IVECO SpA, ElringKlinger AG, Etablissements Franz Colruyt NV, WaterstofNet VZW, Air Liquide Advanced Business, PowerCell Sweden AB, Union Internationale des Transports Routiers, Bayerische Motoren Werke Aktiengesellschaft, Robert Bosch GmbH, Hydrogen Europe

<https://www.h2haul.eu>

PROJECT AND OBJECTIVES

H2Haul brings together two major European truck OEMs (IVECO and VDL) and three 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 H2Haul is to prove that hydrogen trucks can be a zero-emission and zero-carbon solution for Europe's trucking needs and, 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.

NON-QUANTITATIVE OBJECTIVES

H2Haul 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.
- Homologate three fuel cell truck types to certify that they are safe to use on Europe's roads. Truck OEMs are working closely with hydrogen safety experts and the relevant certification bodies.
- Develop the business case for the further roll-out of heavy-duty fuel cell trucks, providing a valuable database of real-world performance information and insights into the next steps required for the commercialization of this sector. Analysis will be carried out to highlight the economics of more ambitious deployments of many tens of vehicles or more.

- Prepare the European market for the further roll-out of fuel cell trucks through communication and the dissemination of results to a wide audience of relevant stakeholders.

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 hydrogen-refuelling stations (HRSs).
- The first project HRS was deployed.
- The second observer group meeting took place.

FUTURE STEPS AND PLANS

- H2Haul will deploy the VDL and IVECO trucks. The first batches of trucks will be deployed by the end of 2022. The first VDL truck will be delivered to Colruyt in spring 2022 to start commercial operation. The remaining VDL trucks will be deployed by autumn 2022. The IVECO Beta trucks are currently being assembled with fuel cells from Bosch and will be deployed in the fourth quarter of 2022. The remaining four Gamma trucks will be deployed by IVECO in the fourth quarter of 2023.
- The project will commission and start the operation of all remaining project HRSs. Currently, one HRS is in operation in Switzerland; end of 2022.
- H2Haul will continue high-profile dissemination and lobbying work through key conferences and events. It will continue work on observer group and other stakeholder engagement.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target
Project's own objectives and MAWP Addendum (2018–2020)	Truck operational period	Months	Start of operation including ramp-up phase: minimum of 24 months
	Truck distance travelled	km	Min. 30 000 km per truck per year, on average, per site
	Truck availability	%	> 90 % on a fleet basis after an initial ramp-up phase of a max. 6 months
	Truck-specific fuel consumption	kg/100 km	< 7.5 kg/100 km, rigid, at 30–50 % load, inner-city delivery (< 25 km/h on average); < 8.5 kg/100 km, tractor with semi-trailer @30–50 % load, long-haul delivery (> 65 km/h on average)
	Availability of station (by project end)	%	99
	Mean distance between failures	km	Fuel cell MDBF of > 2 500 km
	Well-to-wheel CO ₂ emissions of < 50 % of those of diesel trucks	kg of CO ₂ /km	kg of CO ₂ /vehicle-km (per vehicle type, average across fleet) of < 50 % compared with diesel trucks
	Speed of hydrogen dispensing	kg/min	> 2.5 kg/min
	Cost of hydrogen dispensed to HRSs	€/kg	≤ 7.5 €/kg dispensed (excluding taxes) at end of project – in practice, lower values are expected
	Amount of hydrogen dispensed to project trucks	kg/year	> 2 500 kg per truck per year

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H2ME 2

HYDROGEN MOBILITY EUROPE 2



Project ID	700350
PRD 2022 Panel	3 – H2 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 100 015 655.40
Clean H₂ max. contribution	EUR 34 999 548.50
Project period	1/5/2016 – 30/6/2022
Coordinator	Element Energy Limited, United Kingdom
Beneficiaries	R-Hynoca, HysetCo, Réseau GDS, Toyota Norge AS, Toyota Danmark AS, Mercedes-Benz AG, McPhy Energy Italia SRL, Element Energy, Stichting Cenex Nederland, B. Kerkhof & Zn BV, Tech Transports Compagnie, Air Liquide France Industrie, Alphabet Fuhrparkmanagement GmbH, Linde Gas GmbH, Iskenska Vetnisfélagið EHF, Communauté Urbaine du Grand Nancy, Stedin Diensten BV, Société du Taxi Electrique Parisien, H2 MOBILITY Deutschland GmbH & Co KG, HYOP AS, Brintbranchen, New NEL Hydrogen AS, Compagnie Nationale Du Rhône SA, Hydrogène de France, Honda R&D Europe (Deutschland) GmbH, GNVert SAS, AGA AB, Symbio, Air Liquide Advanced Technologies SA, Elogen, Société d'économie mixte des transports en commun de l'agglomération nantaise, Ministerie van Infrastructuur en Waterstaat, Intelligent Energy Limited, Manufacture Francaise des Pneumatiques Michelin, ITM Power (Trading) Limited, Centre of Excellence for Low Carbon and Fuel Cell Technologies, Københavns Kommune, hySOLUTIONS GmbH, McPhy Energy, Mercedes-Benz Fuel Cell GmbH, WaterstofNet VZW, Nissan Motor Manufacturing (UK) Limited, Air Liquide Advanced Business, Renault Trucks SAS, Element Energy Limited, Nel Hydrogen AS, Icelandic New Energy Ltd, Europäisches Institut für Energieforschung EDF-KIT EWIV, Stedin Netbeheer BV, Renault SAS, Bayerische Motoren Werke Aktiengesellschaft, Audi Aktiengesellschaft, Open Energi Limited, Daimler AG, University of Manchester

<http://www.h2me.eu/>


PROJECT AND OBJECTIVES

H2ME 2 brings together actions in eight countries in a 7-year collaboration to deploy 20 hydrogen-refuelling stations (HRSs) and around 1 000 vehicles. The project will perform a large-scale market test of a large fleet of fuel cell electric vehicles operated in real-world customer applications across multiple European regions. In parallel, it will demonstrate that the hydrogen mobility sector can support the wider European energy system via electrolytic hydrogen production. The H2ME initiative is the largest European deployment to date for hydrogen mobility, with 897 vehicles and 40 HRSs deployed.

NON-QUANTITATIVE OBJECTIVES

- A minimum of 1 200 fuel cell vehicles and 20 HRSs were planned by the end of the project.
- The project aims to demonstrate the electrolyser-integrated HRS operating in grid balancing. H2ME 2 has a dedicated work package to assess the way in which electrolytic hydrogen production in the mobility sector can link to the wider energy system.
- H2ME 2 aims to deploy cars, light-duty vans and trucks from OEMs including Mercedes, Honda, Symbio, Hyundai and Toyota.
- H2ME 2 aims to ensure the cross-fertilisation of knowledge acquired in the project. A dedicated work plan and a dissemination and exploitation plan are being used to achieve this.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
HRSs							
Project's own objectives, MAWP Addendum (2018–2020) and AWP 2015	HRS availability	%	98	96		98	2017
	Min. HRS operation	months	36	58	✓	32	
	Hydrogen purity	%	99.99	99.999	✓	99.99	
Fuel cell vehicles							
Project's own objectives, MAWP Addendum (2018–2020) and AWP 2015	Min. vehicle operation during the project	months	36	60	✓	12	2017
	Vehicle availability	%	98	> 99	✓	98	

PROGRESS AND MAIN ACHIEVEMENTS

- There were 500 vehicles and 12 HRSs in operation as of February 2022 (in the H2ME 2 project alone).
- Demonstration is under way for more than 800 vehicles from five OEMs (Mercedes, Honda, Hyundai, Symbio and Toyota) and 50 HRSs from five suppliers across six countries (Denmark, France, Iceland, the Netherlands, Sweden and the United Kingdom) – jointly with H2ME.
- The demonstration of positive business cases under H2ME 2 has led to further commitments from partners to expand fleets in Denmark, Germany and France.
- The project is building a rich dataset for Europe, jointly with H2ME. Since 2016, 19.2 million km have been driven and 243 t of H₂ distributed in 104 000 events (figures from November 2021).

FUTURE STEPS AND PLANS

- All 20 HRSs planned for the project are expected to have been commissioned and be in operation by the end of 2022. Almost all the HRSs to be commissioned have the permits required.
- The last vehicles planned for the project are expected to be deployed in the next 6 months.
- The project will build a solid and growing base of operational data from vehicles and HRSs, and undertake further fact-based analysis of vehicles' and HRSs' performances.
- H2ME and H2ME 2, more than 50 reports have been prepared to date. The projects have prepared a summary report for the end of phase 1 of the initiative.

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H2PORTS

IMPLEMENTING FUEL CELLS AND HYDROGEN TECHNOLOGIES IN PORTS

Project ID	826339
PRD 2022 Panel	3 – H2 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
Clean H ₂ max. contribution	EUR 3 999 947.50
Project period	1/1/2019 – 31/12/2022
Coordinator	Fundación de la Comunidad Valenciana para la Investigación, Promoción y Estudios Comerciales de Valenciaport, Spain
Beneficiaries	Valencia Terminal Europa SA, Cantieri Del Mediterraneo SpA, Hyster-Yale Nederland BV, Atena scarl – Distretto Alta Tecnologia Energia Ambiente, Mediterranean Shipping Company Terminal Valencia SA, Centro Nacional de Experimentación de Tecnologías de Hidrógeno y Pilas de Combustible Consorcio, Grimaldi Euromed SpA, Ballard Power Systems Europe AS, Autoridad Portuaria de Valencia, Enagás SA, Università degli Studi di Napoli Parthenope, Università degli Studi di Salerno, Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile

<https://h2ports.eu/>


PROJECT AND OBJECTIVES

The H2Ports 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 2 years of real operational activities at the port of Valencia, and a mobile hydrogen-refuelling station (HRS) designed and built during the project will provide the required hydrogen. All three elements are currently in advanced stages of building, and the piloting period is planned to start in summer 2022.

NON-QUANTITATIVE OBJECTIVES

- The project aims to disseminate H₂ technologies to the port maritime sector. This goal has been accomplished through the organisation of the stakeholder advisory group.
- H2Ports will gather information on the use of H₂ in port environments.
- It will gather information on the use of H₂ as fuel for vessels.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	HRS daily capacity	kg/day	60	
	Reach stacker's vehicle power	kW	90	✓
	Vehicle power	kW	75	✓

PROGRESS AND MAIN ACHIEVEMENTS

- H2Ports has designed a mobile HRS.
- The project has completed the design and component selection for a fuel cell reach stacker.
- It has completed the design and component selection for a terminal tractor.

FUTURE STEPS AND PLANS

It is planned 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 summer 2022.

HEAVEN

HIGH POWER DENSITY FC SYSTEM FOR AERIAL PASSENGER VEHICLE FUELED BY LIQUID HYDROGEN



Project ID 826247

PRD 2022 Panel 3 – H2 end uses: Transport

Call topic FCH-01-4-2018: Fuel cell systems for the propulsion of aerial passenger vehicle

Project total costs EUR 4 600 881.68

Clean H₂ max. contribution EUR 3 995 305

Project period 1/1/2019 – 31/12/2022

Coordinator Fundación Ayesa, Spain

Beneficiaries Pipistrel Vertical Solutions DOO podjetje za napredne letalske rešitve, H2FLY GmbH, Air Liquide Advanced Technologies SA, ElringKlinger AG, L'Air Liquide SA, Deutsches Zentrum für Luft- und Raumfahrt EV

<https://heaven-fch-project.eu/>

PROJECT AND OBJECTIVES

The overall objective of this project is to address the gap between the research and product stages of a zero-emission fuel-cell-based propulsion technology to achieve emission- 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 will be combined with the high energy density of cryogenic hydrogen storage. It will be advanced up to TRL 6.

NON-QUANTITATIVE OBJECTIVES

- HEAVEN aims to increase the credibility of the solution for the propulsion of passenger aircraft and UAVs.
- The project aims to advance towards zero-emission hydrogen-powered regional commuter airliners.

PROGRESS AND MAIN ACHIEVEMENTS

- The conceptual design of the overall powertrain is complete.
- The full stack test system has been fully integrated into the test bench.
- Aircraft safety studies are ongoing.

FUTURE STEPS AND PLANS

- HEAVEN will finish manufacturing and testing the liquid hydrogen tank system, which is expected to be done in July 2022.
- The project will couple the powertrain system with the liquid hydrogen system (expected to be in progress until October 2022).
- The overall system will be tested (until February 2023).



QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objectives and AWP 2018	FC stack power density in weight	kW/kg	2 kW/kg	2.7 kW/kg (stack including end plates)	
	FC power density in volume	kW/l	3.5 kW/l	4.1 kW/l (stack including end plates)	
	Air subsystem	%	> 50 %	Preliminary results are in compliance with this value but not achieved yet	
	Power converter	kW/kg	8 kW/kg	Preliminary results are in compliance with this value but not achieved yet	
	System lifetime	hours	500 (stack)	N/A	

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HYSHIP

DEMONSTRATING LIQUID HYDROGEN FOR THE MARITIME SECTOR



Project ID 101007205

PRD 2022 Panel 3 – H2 end uses: Transport

Call topic FCH-01-6-2020: Demonstration of liquid hydrogen as a fuel for segments of the waterborne sector

Project total costs EUR 10 796 560

Clean H₂ max. contribution EUR 7 993 942

Project period 1/1/2021 – 31/12/2025

Coordinator Wilh. Wilhelmsen Holding ASA, Norway

Beneficiaries NorSea Group AS, Diana Shipping Services SA, Wilhelmsen Ship Management (Norway) AS, Air Liquide Norway AS, Stolt Tankers BV, Massterly AS, LMG Marin France, LMG Marin AS, Norled AS, Maritime Cleantech, Persee, DNV GL SE, Equinor Energy AS, Kongsberg Maritime AS, DNV AS, University of Strathclyde, National Centre of Scientific Research 'Demokritos', Eidgenössische Technische Hochschule Zürich

<https://hyship.eu/>

PROJECT AND OBJECTIVES

HyShip is building two vessels that will run on liquid hydrogen (LH₂). The vessels will transport goods from port to port along the west coast of Norway, and transport LH₂ for bunkering stations for other vessels/trucks running on hydrogen. The project aims to replace trucks on the roads between the ports, demonstrate the use of LH₂ on a vessel and distribute LH₂ to ports to facilitate a LH₂ supply chain. The main key performance indicator of the project is to demonstrate 3 000 hours of operation of 3 MW fuel cells. The design of the vessel is ongoing, and the vessel has not been ordered yet.

NON-QUANTITATIVE OBJECTIVES

- HyShip aims to conceptually design a full range of vessel and hydrogen systems.
- The project aims to develop and describe a business ecosystem with a timeline for cost-efficient operation.
- HyShip aims to integrate the demonstrator into a larger socio-technical system – with business models, policy models and LH₂ supply – that will help move towards use of LH₂.

- The project aims to use further RHODA ship design methods, lowering the cost of estimating complex projects with novel fuel and infrastructure, allowing real-time data collection on the effects of the use of novel fuels (no real-time data provided yet).
- It aims to develop input to the International Maritime Organization, which will help the systems transition to its rules instead of following the alternative design approach.

PROGRESS AND MAIN ACHIEVEMENTS

The preliminary design of vessel and liquid hydrogen propulsion systems is complete.

FUTURE STEPS AND PLANS

- The ship building contract will be signed.
- The vessels will be delivered.
- Vessel operations will begin.

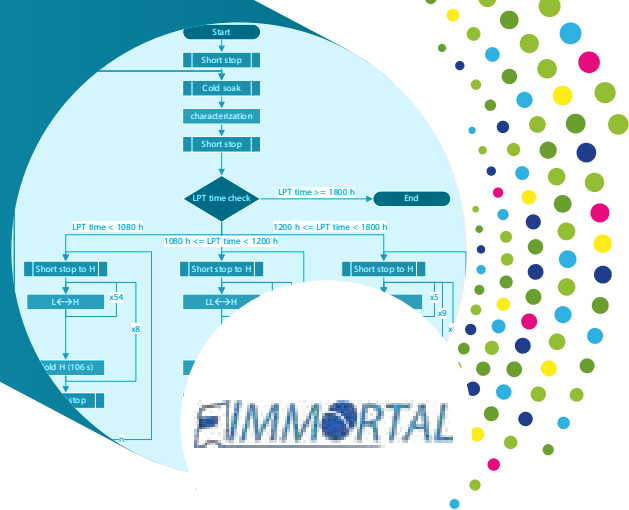
QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Fuel cell power output	MW	3.0	
	Hours of operation of LH ₂ -powered propulsion	hours	3 000	
	Develop an intelligent energy management system that reduces the CAPEX of the energy system by > 5 %	%	5	
	Reduction of > 40 % of cost of design and ship integration cost related to the hydrogen/fuel cell systems themselves	%	40	



IMMORTAL

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



Project ID 101006641

PRD 2022 Panel 3 – H2 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

Clean H₂ max. contribution EUR 3 825 927.50

Project period 1/1/2021 – 31/12/2023

Coordinator Centre national de la recherche scientifique, France

Beneficiaries FPT Motorenforschung AG, Université de Montpellier, FPT Industrial SpA, Johnson Matthey Fuel Cells Limited, Pretexo, Albert-Ludwigs-Universität Freiburg, Robert Bosch GmbH, Johnson Matthey plc, AVL List GmbH

<https://immortal-fuelcell.eu/>

PROJECT AND OBJECTIVES

IMMORTAL aims to develop high-performance and high-durability membrane electrode assemblies (MEAs), and their components, specifically designed for heavy-duty truck application. By month 14, an initial set of accelerated and load profile cell and stack tests had been developed and applied to baseline MEAs. Selected actual truck missions were simulated to produce load profiles that will be used to produce load-profile testing procedures. Materials (support, catalyst, membrane) were developed that will be integrated into an initial heavy-duty MEA for single-cell and short-stack testing.

NON-QUANTITATIVE OBJECTIVES

IMMORTAL aims to contribute to activities on Mission Innovation's hydrogen innovation challenge through cooperation with the US Department of Energy's Million Mile Fuel Cell Truck Consortium. Several workshops have been held with the consortium, and with Japan's fuel cell platform, which included discussions

on, inter alia, heavy-duty stressors, the second-generation Toyota Mirai and advanced characterisation techniques.

PROGRESS AND MAIN ACHIEVEMENTS

- IMMORTAL has developed catalysts with improved retention of mass activity compared with reference Pt/C catalysts.
- The project has simulated actual heavy-duty truck missions, leading to load profiles that inform cell and stack test protocol development.

FUTURE STEPS AND PLANS

- IMMORTAL will deliver materials for initial heavy-duty specific-catalyst-coated membranes (expected to take place in 2022).
- It will deliver initial heavy-duty specific-catalyst-coated membranes for single-cell, stack-accelerated and load-profile testing as part of work package 2 (expected in 2022).

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
AWP 2020	Cell voltage at 1.77 A/cm ²	V	0.675	0.607		0.675	2021
	Durability	hours	30 000 hours with < 10 % degradation	Durability testing is planned in RP2; MEAs have been developed for heavy-duty trucks		8 500 hours with < 10 % degradation	2020
Project's own objectives	Catalyst surface area and mass activity	cm ² /g of Pt and A/mg of Pt	Exceeding values of reference Pt and better retention after accelerated degradation cycles than reference Pt/C	Two catalyst designs achieve this objective	✓	N/A	N/A

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JIVE

JOINT INITIATIVE FOR HYDROGEN VEHICLES ACROSS EUROPE



Project ID	735582
PRD 2022 Panel	3 – H2 end uses: Transport
Call topic	FCH-01-9-2016: Large scale validation of fuel cell bus fleets
Project total costs	EUR 102 467 226.91
Clean H ₂ max. contribution	EUR 32 000 000
Project period	1/1/2017 – 31/12/2022
Coordinator	Element Energy Limited, United Kingdom
Beneficiaries	RebelGroup Advisory BV, In-der-City-Bus GmbH, ESWE Verkehrsgesellschaft mbH, Mainzer Verkehrsgesellschaft mbH, Verkehrs-Verbund Mainz-Wiesbaden Gesellschaft mit beschränkter Haftung, Regionalverkehr Köln GmbH, EUE ApS, Dundee City Council, West Midlands Travel Limited, Società autobus servizi d'area SpA AG, Herning kommune, WSW mobil GmbH, Rīgas Satiksme SIA, Trentino Trasporti SpA, EE Energy Engineers GmbH, Gelderland, Sphera Solutions GmbH, hySOLUTIONS GmbH, Aberdeen City Council, Südtiroler Transportstrukturen AG, HyCologne Wasserstoff Region Rheinland EV, London Bus Services Limited, Planungsgruppe Energie und Technik GbR, Birmingham City Council, Fondazione Bruno Kessler, Union Internationale des Transports Publics, Hydrogen Europe

<http://www.fuelcellbuses.eu/projects/jive>

PROJECT AND 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 142 FCBs in eight 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 for 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 objective, all buses deployed thus far in the project are replacing diesel technology. This means that the buses will lead to CO₂ abatement and will not simply operate as a 'visible extra'.

PROGRESS AND MAIN ACHIEVEMENTS

- To date, all 142 buses have been ordered from four bus manufacturers.
- In total, 121 of these buses are currently in operation (85 %).

FUTURE STEPS AND PLANS

- By the end of 2022, all buses are expected to be operational.
- To date, two cities do not yet have operational buses (one of the cities has faced unexpected events that have led to considerable delays, and the other city is expected to have operational buses by summer 2022).

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives and AWP 2016	Vehicle operational lifetime	years	8	
	Distance travelled	km/year	≥ 44 000	
	Operating hours per fuel cell system	hours	> 20 000	
	Availability	%	> 90	
	MDBF	km	> 2 500	
	Specific fuel consumption	kg/100 km	> 9	
	Efficiency	%	> 42	
	Vehicle OPEX	euro	Max. 100 % more than diesel bus OPEX	
	Vehicle CAPEX	euro	< 650 000	✓

JIVE 2

JOINT INITIATIVE FOR HYDROGEN VEHICLES ACROSS EUROPE 2



Project ID	779563
PRD 2022 Panel	3 – H2 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 105 520 120.12
Clean H ₂ max. contribution	EUR 25 000 000
Project period	1/1/2018 – 31/12/2023
Coordinator	Element Energy Limited, United Kingdom
Beneficiaries	Transdev Occitanie Ouest, HYPOT, Občina Šoštanj, Element Energy, Engie Energie Services, Communauté d'Agglomération de L'Auxerrois, Connexion Vloot BV, Rheinsche Bahngesellschaft Aktiengesellschaft, Société publique locale d'exploitation des transports publics et des services à la mobilité de l'agglomération paloise, Strætó bs, Twynstra Gudde Mobiliteit & Infrastructuur BV, Openbaar Lichaam OV-Bureau Groningen en Drenthe, Pau Béarn Pyrénées Mobilités, Landstinget Gävleborg, RebelGroup Advisory BV, Regionalverkehr Köln GmbH, Dundee City Council, Connexion Openbaar Vervoer NV, WSW Mobil GmbH, Rigas Satiksme SIA, Mestna občina Velenje, Kolding kommune, Transports de Barcelona SA, Sphera Solutions GmbH, Brighton & Hove Bus and Coach Company Limited, Ruter AS, Provincie Zuid-Holland, Petroleos De Portugal – Petrogal SA, Vätgas Sverige Ideell Förening, Noord-Brabant Provincie, Union internationale des transports publics, Hydrogen Europe

<http://www.fuelcellbuses.eu/projects/jive-2>

PROJECT AND OBJECTIVES

The JIVE 2 project aims to deploy 152 fuel cell buses (FCBs). Combined, the JIVE projects will deploy nearly 300 FCBs in 18 cities across Europe by the early 2020s – 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 CO₂ abatement and will not simply operate as a 'visible extra'.

PROGRESS AND MAIN ACHIEVEMENTS

- To date, all 156 buses have been ordered.
- To date, 86 buses are operational, which represents 55 % of all the buses.

FUTURE STEPS AND PLANS

- By the end of 2022, all buses are expected to be operational.
- To date, four cities do not yet have operational buses as they are still waiting for their buses to be delivered. The last buses are expected to be delivered in November 2022.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives and AWP 2017	Vehicle operational lifetime	years	8	
	Distance travelled	km/bus	≥ 44 000	
	Operating hours per fuel cell system	hours	> 20 000	
	Availability	%	> 90	
	MDBF	km	> 2 500	
	Specific fuel consumption	kg/100 km	> 9	
	Efficiency	%	> 42	
	Vehicle OPEX	euro	Max. 100 % more than diesel bus OPEX	
	Vehicle CAPEX	euro	< 650 000	✓

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MARANDA

MARINE APPLICATION OF A NEW FUEL CELL POWERTRAIN VALIDATED IN DEMANDING ARCTIC CONDITIONS



Project ID	735717
PRD 2022 Panel	3 – H2 end uses: Transport
Call topic	FCH-01-5-2016 – Develop new complementary technologies for achieving competitive solutions for marine applications at an economic scale of implementation
Project total costs	EUR 3 704 757.50
Clean H ₂ max. contribution	EUR 2 939 457.50
Project period	1/3/2017 – 28/2/2021
Coordinator	Teknologian tutkimuskeskus VTT Oy, Finland
Beneficiaries	Swiss Hydrogen SA, Persee, OMB Sileri SpA, PowerCell Sweden AB ABB Oy, Suomen Ympäristökeskus
http://projectsites.vtt.fi/sites/maranda	

PROJECT AND OBJECTIVES

In the MARANDA project, an emission-free hydrogen-fuelled proton-exchange-membrane-fuel-cell-based hybrid powertrain system (3 × 82.5 kW AC) was developed for marine applications and was validated in test benches and at a durability test site, as approval for testing the systems in the Aranda vessel was not granted. The project increased the market potential of hydrogen fuel cells in the marine sector. General business cases for different marine and harbour actors or fuel cell business actors were created.

NON-QUANTITATIVE OBJECTIVES

- The MARANDA project has already had a significant impact on the development of regulations, codes and standards.
- The fuel cell systems should be able to withstand the shocks, vibrations, saline environment and ship motions commonly encountered on the water, and other marine-application-relevant requirements. Fuel cell systems and hydrogen storage are designed to withstand these conditions.
- MARANDA aimed to evaluate the economic and environmental impacts for a prospective customer. A report on the business analysis of hydrogen fuel cells for marine applications has been prepared.
- The project aimed to formulate an initial go-to-market strategy. The report on the business analysis includes this strategy.

- MARANDA aimed to map opportunities for future demonstration actions. This is included in a report on the business analysis of hydrogen fuel cells for marine applications.

PROGRESS AND MAIN ACHIEVEMENTS

- Three fuel cell systems from Swiss Hydrogen were assembled, delivered to VTT, integrated in containers, and tested at VTT and at the durability test site.
- A significant improvement in stack durability has been shown by PowerCell Sweden.
- Containers and equipment for the integration of fuel cell systems were designed, manufactured and tested, including all safety systems.

FUTURE STEPS AND PLANS

The final test runs were carried out in March–May 2022; 80 % of the test runs had been completed by 28 February 2022.



QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
AWP 2016	Fuel cell system power	kW	75	75	✓
	Stack durability	mV/1 000 h	4.6	1.7	✓
	Fuel-to-electricity efficiency (alternating current)	%	48	42	✓

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MORELIFE

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



Project ID	101007170
PRD 2022 Panel	3 – H2 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
Clean H ₂ max. contribution	EUR 3 499 913.75
Project period	1/9/2019 – 31/8/2024
Coordinator	AVL List GmbH, Austria
Beneficiaries	EKPO Fuel Cell Technologies GmbH, Mebius, Raziskovalno razvojna dejavnost, zastopanje in trgovina, DOO, Nedstack Fuel Cell Technology BV, Univerza v Ljubljani, Technische Universiteit Eindhoven, Technische Universität München

<https://morelife-info.eu/>

PROJECT AND OBJECTIVES

The MORELife project is addressing the need for highly efficient material utilisation, maximised durability and optimised matching of the operation conditions for a proton-exchange membrane fuel cell in heavy-duty applications. The objectives are to:

- perform accelerated stress tests for the shortened test duration for lifetime verification;
- make improvements at material and operation strategy levels;
- create advanced degradation models;
- find the optimised and validated operating conditions based on the improved materials;
- achieve a fuel cell predicted lifetime of 30 000 hours.

PROGRESS AND MAIN ACHIEVEMENTS

The project is currently in an early phase.

FUTURE STEPS AND PLANS

- MORElife will establish in situ and ex situ tests and accelerated stress testing protocols. For material analyses, these will target the mechanistic understanding relevant to heavy-duty application.
- Catalyst-coated membrane preparation on two selected membranes will be carried out. Issue-specific material improvements will be made.
- Membrane electrode assemblies based on innovative materials will be made for assessment in single cells, five-cell small-active-area stacks and the industry-relevant 10-cell short stack.

PEGASUS

PEMFC BASED ON PLATINUM GROUP METAL FREE STRUCTURED CATHODES



Project ID	779550
PRD 2022 Panel	3 – H2 end uses: Transport
Call topic	FCH-01-2-2017: Towards next generation of PEMFC: Non-PGM catalysts
Project total costs	EUR 2 829 016.88
Clean H ₂ max. contribution	EUR 2 829 016.88
Project period	1/2/2018 – 31/6/2021
Coordinator	Commissariat à l'énergie atomique et aux énergies alternatives, France
Beneficiaries	Heraeus Amloy Technologies GmbH, Toyota Motor Europe NV, IRD Fuel Cells A/S, École nationale supérieure des mines de Paris, Technische Universität München, Association pour la recherche et le développement des méthodes et processus industriels, Deutsches Zentrum für Luft- und Raumfahrt EV, Agencia Estatal Consejo Superior de Investigaciones Científicas

<http://www.pegasus-pemfc.eu/>

PROJECT AND OBJECTIVES

PEGASUS is exploring a promising route towards the removal of Pt and other critical raw materials (CRM) from proton-exchange membrane fuel cells (PEMFCs), and their replacement by non-critical elements and structures enabling efficient and stable electrocatalysis.

NON-QUANTITATIVE OBJECTIVES

- PEGASUS aims to implement new techniques to characterise platinum-group-metal (PGM)-free catalysts for oxygen reduction reaction (ORR) in PEMFCs. Atomic force microscopy (AFM) was combined with scanning electrochemical microscopy (SECM) to quantify the ORR activity of the PGM catalyst at agglomerate level.
- The project aims to perform diagnosis to quantify the O₂, H⁺ and e⁻ transport achieved in PGM-free cathodes.

- PEGASUS aims to achieve benchmark PGM catalysts integrating catalysts from other research groups (US Department of Energy, New Energy and Industrial Technology Development Organization).
- The project delivered a workshop to share the results.

PROGRESS AND MAIN ACHIEVEMENTS

- PEGASUS achieved synthesis of PGM-free catalysts.
- It diagnosed and characterised the PGM-free cathodes for PEMFCs.
- Life cycle analysis was performed on the PGM-free catalysts.

FUTURE STEPS AND PLANS

The project has finished.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SoA result achieved to date (by others)
AWP 2017	Catalyst activity (i _{geo} @ 0.9 V under air)	mA/cm ²	44	6.5		
	Catalyst activity (i _{geo} @ 0.7 V under air)	mA/cm ²	600	280		N/A
	Catalyst activity @ 0.9 V (iR-free under O ₂)	mA/cm ²	75	17.5		
	Diagnosis and in situ characterisation of PGM-free cathode's H ⁺ resistance and O ₂ diffusion	N/A	N/A	N/A		200
Project's own objectives	Implementation of SECM	N/A	N/A	N/A	✓	N/A
	Multigram production of catalyst for one batch	g	5	5		N/A
	LCA/Techno-economic assessment	N/A	N/A	N/A		

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REVIVE

REFUSE VEHICLE INNOVATION AND VALIDATION IN EUROPE



REVIVE

Project ID	779589
PRD 2022 Panel	3 – H2 end uses: Transport
Call topic	FCH-01-7-2017: Validation of fuel cell trucks for the collect of urban wastes
Project total costs	EUR 9 278 697.55
Clean H ₂ max. contribution	EUR 4 993 851
Project period	1/1/2018 – 31/12/2024
Coordinator	Tractebel Engineering, Belgium
Beneficiaries	Gemeente Noordenveld, Tractebel Impact Belgium SA, Gemeente Groningen, Saver NV, PreZero Nederland Holding BV, Azienda Servizi Municipalizzati di Merano SpA, Servizi Energia Ambiente Bolzano SpA, Swiss Hydrogen SA, Renova Aktiebolag, E-Trucks Europe, Gemeente Breda, Symbio, Stad Antwerpen, WaterstofNet VZW, PowerCell Sweden AB, Element Energy Limited, Proton Motor Fuel Cell GmbH, Gemeente Amsterdam, Commissariat à l'énergie atomique et aux énergies alternatives

<https://h2revive.eu/>

PROJECT AND OBJECTIVES

REVIVE will significantly advance the state of development of fuel cell refuse trucks by integrating fuel cell powertrains into 14 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, three trucks are in operation, and the remaining trucks will be deployed in the coming months.

NON-QUANTITATIVE OBJECTIVES

- The project aims to involve four fuel cell suppliers. Currently, two EU fuel cell suppliers are involved in the project: Proton Motor and PowerCell Sweden.
- The project aims to demonstrate a route to high utilisation of hydrogen-refuelling stations to support roll-out of H₂ mobility

for light vehicles. Even with limited running hours, the three trucks deployed in the project have already consumed 1 t of H₂ during the project.

PROGRESS AND MAIN ACHIEVEMENTS

- All trucks are in the building phase.
- The first Proton Motor fuel cell system has been delivered and successfully integrated.
- The first REVIVE trucks have been deployed.

FUTURE STEPS AND PLANS

- **Deployment preparation.** At project consortium level, sharing of experience and relevant documentation is taking place to fully prepare for truck deployment.
- **Increased dissemination activities.** To catch up following the delays experienced in 2020, a plan for dissemination will be developed.
- **Decrease of teething issues.** The trucks are being tested thoroughly before delivery.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
AWP 2017	Number of FCs deployed in the project	–	15	14	
	Tank-to-wheel efficiency	%	50	N/A	
	Lifetime	hours	25 000	N/A	
	Availability	%	90	N/A	
	Driving Distance Between Failures (MDBF)	km	3 500	N/A	
	Fuel cell power	kW	> 40	45	✓

SH2APED

STORAGE OF HYDROGEN: ALTERNATIVE PRESSURE ENCLOSURE DEVELOPMENT



Project ID	101007182
PRD 2022 Panel	3 – H2 end uses: Transport
Call topic	FCH-01-1-2020: Development of hydrogen tanks for electric vehicle architectures
Project total costs	EUR 1 993 550
Clean H ₂ max. contribution	EUR 1 993 550
Project period	1/1/2021 – 31/12/2023
Coordinator	Plastic Omnium Advanced Innovation and Research, Belgium
Beneficiaries	MISAL SRL, Optimum CPV, OMB Sileri SpA, Bundesanstalt Für Materialforschung und -Prüfung, University of Ulster

<http://sh2aped.eu/>

PROJECT AND OBJECTIVES

The goal of the SH2APED project is to develop and test at technology readiness level 4 a conformable and cost-effective hydrogen 70 MPa storage system with increased efficiency and unprecedented safety performance.

NON-QUANTITATIVE OBJECTIVES

Regarding certification procedures, the project aims to contribute to the revision of regulations.

PROGRESS AND MAIN ACHIEVEMENTS

- The first assembly design has been finalised (several types are available). The vessel design has also been completed and made available.
- Vessel prototypes are available.
- SH2APED has designed pressure container elements (liner–boss reinforcement).
- System testing of the model's reaction to fire is in progress.

FUTURE STEPS AND PLANS

The frame design is ongoing.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
Project's own objectives	H ₂ storage volume for estimated design space	%	> 45	43	⚙️	41	2021
	Low-cost process for liner	euro	1 million	1 million	✓	3 million	2021
	Burst pressure (R134)	MPa	> 157.5	170	⚙️	157.5	2021

SHIPFC

PILOTING MULTI MW AMMONIA SHIP FUEL CELLS



Project ID	875156
PRD 2022 Panel	3 – H2 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
Clean H ₂ max. contribution	EUR 9 975 477.50
Project period	1/1/2020 – 31/12/2025
Coordinator	Maritime Cleantech, Norway
Beneficiaries	Eidesvik Shipping AS, Wärtsilä Gas Solutions Norway AS, Sustainable Energy AS, North Sea Shipping AS, Star Bulk Shipmanagement Co (Cyprus) Ltd, Wärtsilä Norway AS, Capital-Executive Ship Management Corp, Persee, Prototech AS, Equinor Energy AS, Yara International ASA, University of Strathclyde, National Centre of Scientific Research 'Demokritos', Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung EV

<https://shipfc.eu/>

PROJECT AND OBJECTIVES

ShipFC's main mission is to prove and show 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. The onboard fuel system design is in progress, together with integration design for the fuel cell power system. ShipFC is building the knowledge base for the development of a global green ammonia fuel infrastructure.

NON-QUANTITATIVE OBJECTIVES

- ShipFC aims to integrate ammonia fuel cell and fuel systems into ship power systems. The integrated ship design is under development. Initial discussions with actors from the industry are complete and follow-up actions have been identified. The detailed design will contribute to updated knowledge in the industry, as this is the first vessel with MW-scale ammonia-powered solid oxide fuel cells (SOFCs) onboard.
- The project aims to demonstrate wider use of the system and scale-up of the system to + 20 MW. The first iteration design for the 5 000 TEU container ship has been established. As the detailed designs of all systems for Viking Energy progress, the container ship design will be modified through several iterations.

PROGRESS AND MAIN ACHIEVEMENTS

- The project has signed an agreement for the delivery of green ammonia fuel for the duration of the project.
- Conceptual designs for the fuel system have been developed.
- The preliminary SOFC module and integrated system designs are complete.

FUTURE STEPS AND PLANS

- ShipFC will scale up and test the SOFC.
- The SOFC is currently undergoing laboratory-scale testing, in preparation for large-scale tests. By November 2023, the full-sized 2 MW SOFC will have been tested.



QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Target achieved?
Project 's own objectives	Greenhouse gas reduction by using ammonia fuel	%	70	
	Ammonia SOFC system power	MW	2	
	MW-scale SOFC operational experience	hours	3 000	

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STASHH

STANDARD-SIZED HEAVY-DUTY HYDROGEN



Project ID	101005934
PRD 2022 Panel	3 – H2 end uses: Transport
Call topic	FCH-01-4-2020: Standard sized FC module for heavy duty applications
Project total costs	EUR 14 514 575.80
Clean H ₂ max. contribution	EUR 7 500 000
Project period	1/1/2021 – 30/6/2024
Coordinator	Sintef AS, Norway
Beneficiaries	Damen Global Support BV, FEV Software and Testing Solutions GmbH, VDL Energy Systems, Plastic Omnium New Energies Wels GmbH, Future Proof Shipping BV, Hyster-Yale Italia SpA, FCP Fuel Cell Powertrain GmbH, VDL Enabling Transport Solutions BV, Hydrogenics GmbH, Freudenberg FST GmbH, Aktiebolaget Volvo Penta, Symbio, Scheepswerf Damen Gorinchem BV, Intelligent Energy Limited, Volvo Construction Equipment AB, WaterstofNet Vzw, Ballard Power Systems Europe AS, Solaris Bus & Coach Spolka Z Ograniczona Odpowiedzialnoscia, Proton Motor Fuel Cell GmbH, Toyota Motor Europe NV, Cetena SpA – Centro per gli Studi di Tecnica Navale, Nedstack Fuel Cell Technology BV, FEV Europe GmbH, Alstom Transport SA, AVL LIST GmbH, Volvo Technology AB, Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek (TNO), Commissariat à l'énergie atomique et aux énergies alternatives

<https://stashh.eu/>

PROJECT AND OBJECTIVES

StasHH's objectives are to agree to 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 – and several partners are already developing prototypes.

NON-QUANTITATIVE OBJECTIVES

- The project aims to disseminate the standard. This has recently started, as the standard was only recently fixed.
- StasHH plans to update the standard based on experience in 2023.

PROGRESS AND MAIN ACHIEVEMENTS

- A standard definition has been agreed.
- StasHH has created a regulations, codes and standards overview.

FUTURE STEPS AND PLANS

- The fuel cell module prototypes will be constructed (expected to be completed in 2022). Some partners are ahead of schedule and some are behind owing to difficulties in aligning with internal schedules.
- Prototype testing will take place at FEV and TNO premises (planned for 2023).

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
	Number of sizes	–	≤ 3	3	
AWP 2020	Number of fuel cell module partners	–	7	11	✓
	Fuel cell module power rating	kW	30–100	30–200	

TAHYA

TANK HYDROGEN AUTOMOTIVE



Project ID	779644
PRD 2022 Panel	3 – H2 end uses: Transport
Call topic	FCH-01-3-2017: Improvement of compressed storage systems in the perspective of high volume automotive application
Project total costs	EUR 3 996 943.75
Clean H ₂ max. contribution	EUR 3 996 943.75
Project period	1/1/2018 – 30/6/2021
Coordinator	Optimum CPV, Belgium
Beneficiaries	AbsisKey, Polarixpartner GmbH, Anleg GmbH, Raigi SAS, Bundesanstalt für Materialforschung und prüfung, Technische Universität Chemnitz, Volkswagen Aktiengesellschaft

<http://tahya.eu/>

PROJECT AND OBJECTIVES

The TAHYA project, mainly led by industrial partners already involved in producing and manufacturing hydrogen solutions for the automotive and aviation industries, focused on the development of a complete, competitive and innovative European H₂ storage system (a cylinder with a mounted on tank valve with all integrated functionalities) for automotive applications outperforming the current Asian and US models.

NON-QUANTITATIVE OBJECTIVES

The orbital winding process can be used for the production of tubular component structures.

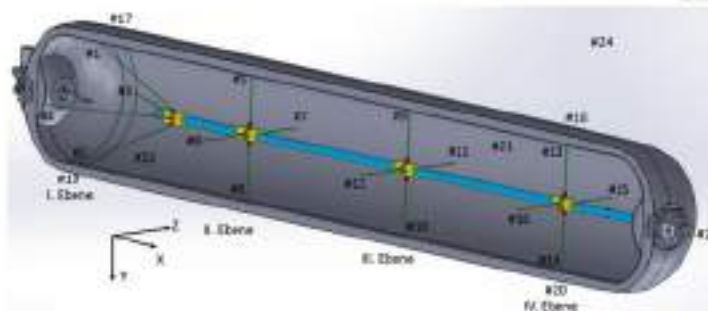
PROGRESS AND MAIN ACHIEVEMENTS

- TAHYA has created a compatible H₂ storage system that is high performing, safe and environmentally responsible.
- The project has created a cost-competitive H₂ storage system for mass production.
- Regulations, codes and standards activities proposed updates to international safety standard GRT13.

FUTURE STEPS AND PLANS

The project finished in June 2021. All objectives were achieved.

© TAHYA, 2021



To carry out the experimental filling test, a measuring system to determine pressure and temperature inside TAHYA's 127-litre type IV cylindrical pressure vessel was produced and assembled at Technische Universität Chemnitz.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
MAWP Addendum (2018–2020)	Gravimetric efficiency of the storage system	%	5.3 %	6.5 %		5.9 %	2021
	Storage cost per kg of hydrogen	€/kg	500	450	✓	N/A	N/A
Project's own objectives	Industrialisation scenario	systems/year	20 000	20 000		30 000	2020

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THOR

THERMOPLASTIC HYDROGEN TANKS OPTIMISED AND RECYCLABLE



Project ID	826262
PRD 2022 Panel	3 – H2 end uses: Transport
Call topic	FCH-01-3-2018: Strengthening of the European supply chain for compressed storage systems for transport applications
Project total costs	EUR 2 884 330.29
Clean H ₂ max. contribution	EUR 2 853 958.75
Project period	1/1/2019 – 30/9/2022
Coordinator	Faurecia Systemes d'Echappement SAS, France
Beneficiaries	ETIM, Covess NV, Cetim Grand Est, École Nationale Supérieure de Mécanique et d'Aérotechnique, Sirris het collectief centrum van de technologische industrie, Rina Consulting – Centro Sviluppo Materiali SpA, Centre technique des industries mécaniques, Université de Poitiers, L'Air Liquide SA, Norges Teknisk-Naturvitenskapelige Universitet, Centre national de la recherche scientifique

<https://thor-fch2.eu/>

PROJECT AND OBJECTIVES

The project aims to validate the technology and its associated process for a recyclable thermoplastic composite tank for the storage of high-pressure gaseous hydrogen for mobility.

NON-QUANTITATIVE OBJECTIVES

- THOR will conduct health monitoring using optical fibres, for temperature control and fire detection. Tests were scheduled to take place in July 2022.
- The project aims to create a recycled panel of thermoplastic reinforced with carbon fibres. Recycling activities are scheduled to take place at the end of the project. The performance of the panels will be tested to define their best use.
- Recyclability of the tanks.

- The project is working on the reuse of the end-of-life tank with a recycling process for producing carbon-fibre composite sheets (preparation of the material and process for the manufacturing of the reused sheets).

PROGRESS AND MAIN ACHIEVEMENTS

- The tanks have been prepared.
- Recycling has been carried out.

FUTURE STEPS AND PLANS

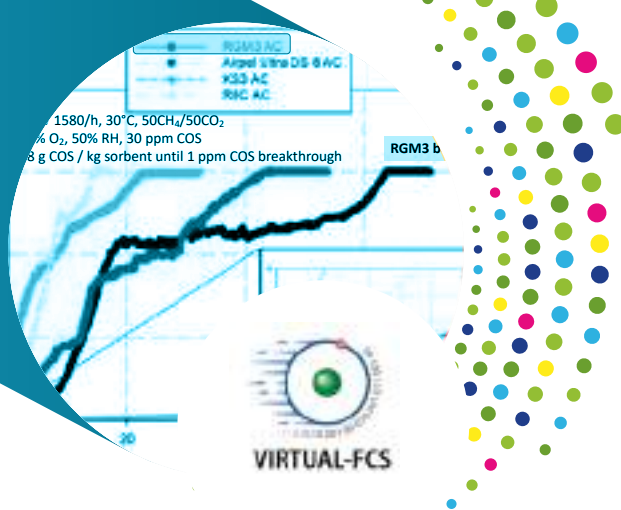
- THOR will finalise the tanks preparation to test the new winding pattern link to the new matrix. This will involve testing the tanks (at ambient, cycling and extreme temperatures).
- The project will perform burst tests, a cycling test at ambient and critical temperatures, and bonfire tests.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
MAWP (2014–2020)	Gravimetric efficiency	%	> 6 %	—	
	Burst pressure	bars	1 575	1 460	
	Cost of tanks	€/kg of H ₂	400	N/A	

VIRTUAL-FCS

VIRTUAL & PHYSICAL PLATFORM FOR FUEL CELL SYSTEM DEVELOPMENT



Project ID	875087
PRD 2022 Panel	3 – H2 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
Clean H ₂ max. contribution	EUR 1 897 806.25
Project period	1/1/2020 – 31/12/2022
Coordinator	Sintef AS, Norway
Beneficiaries	Banke Aps, Vivarail Ltd, Communauté d'universités et d'établissements université Bourgogne Franche-Comté, Seam AS, Ballard Power Systems Europe AS, École nationale supérieure de mécanique et des microtechniques, Solaris Bus & Coach Spolka Z Ograniczona Odpowiedzialnoscia, Université de technologie de Belfort-Montbéliard, Université De Franche-Comté

<http://www.sintef.no/projectweb/virtual-fcs/>

PROJECT AND 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 parts 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 for a significant reduction of 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 cyber-physical hardware integration.
- The project has demonstrated fuel cell electric vehicle simulations.
- It has also demonstrated real-time system simulation.

FUTURE STEPS AND PLANS

- The project will demonstrate real-time system emulation. The project will demonstrate this capability by emulating a full multistack 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 real load cycles on the physical stack.
- The project will integrate components from the physical hybrid system into the system simulated in the software tools and those emulated on a controller.
- The effect of the energy management strategy on system degradation will be investigated. To validate the mixed software hardware development approach, new energy management systems will be explored. Using the software tools developed in the project, simulations of systems will take place using different control strategies and will examine how this affects the system's lifetime.
- VIRTUAL-FCS will perform balance-of-plant prognostics model validation. The project will develop a reduced-order model that can describe proton-exchange membrane fuel cell stack performance and degradation.
- The project will produce explanatory webinars and blog posts to accompany every release of new code. It will also organise a workshop, the focus of which will be practical training in the use of the developed platform.

ZEFER

ZERO EMISSION FLEET VEHICLES FOR EUROPEAN ROLL-OUT

Project ID	779538
PRD 2022 Panel	3 – H2 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 17 508 573.08
Clean H ₂ max. contribution	EUR 4 998 843
Project period	1/9/2017 – 31/8/2022
Coordinator	Element Energy Limited, United Kingdom
Beneficiaries	Air Liquide Advanced Technologies GmbH, Linde GmbH, Element Energy, Green Tomato Cars Limited, Breath, Air Liquide France Industrie, L'Air Liquide Belge, Societe du Taxi Electrique Parisien, Air Liquide Advanced Technologies SA, ITM Power (Trading) Limited, Centre of Excellence for Low Carbon and Fuel Cell Technologies, Air Liquide Advanced Business, Ville de Paris, Linde AG, Bayerische Motoren Werke Aktiengesellschaft

<https://zefer.eu/>

PROJECT AND OBJECTIVES

ZEFER aims to demonstrate viable business cases for fuel cell electric vehicles (FCEVs) in high-mileage fleet applications. The project aims to deploy 180 FCEVs into taxi, private-hire and emergency-service operations in three major European cities in which their operational benefits and zero-emission credentials can be monetised. The vehicles will use existing hydrogen-refuelling station (HRS) networks to increase local utilisation levels and improve the business case for HRS operators.

NON-QUANTITATIVE OBJECTIVES

ZEFER aims to:

- Develop comprehensive lessons from the deployment on topics such as customer acceptance, the business case for FCEVs and the technical performance of HRSs and FCEVs under high utilisation.
- Increase the confidence of investors and policymakers in FCEV and HRS roll-out. ZEFER has proven that FCEVs and HRSs can meet the demands of high-mileage fleet operations.
- Maintain or even increase the participation of SMEs in Clean Hydrogen JU projects. Currently, 50 % of ZEFER partners are SMEs, and 84 % of the project funding targets SMEs.
- Reduce the production cost of FC systems in transport applications. The bulk procurement of FCEVs is expected to reduce FCEVs' costs to their lowest level.
- Demonstrate, at utilisation levels, a significantly longer lifetime of fuel cells in FCEVs than that of those currently deployed, to compete with conventional technologies.
- Increase the energy efficiency of hydrogen production while reducing operating and capital costs. ZEFER aims to reduce the hydrogen cost at the pump to < 10 €/kg.

The project also aims to trigger further cost reductions by encouraging investment in the low-cost green production systems.

PROGRESS AND MAIN ACHIEVEMENTS

- All 180 FCEVs have been deployed into everyday operation in Paris, London and Copenhagen (60 in each).
- Most of the HRS upgrades have been completed, leading to improvements in the technical performance and customer experience of HRSs.
- All deployment partners in the project have plans to scale up their FCEV fleets as a result of the ZEFER project.

FUTURE STEPS AND PLANS

- ZEFER will complete the HRS upgrades required in Paris. The initial plan for the upgrade has been delayed due to permit procedures taking longer than anticipated. As a mitigation plan, Air Liquide will perform different upgrades at other Parisian HRSs (Porte de la Chapelle and Roissy-en-France).
- The project will continue collecting data on the FCEVs and HRSs to better understand how performance is affected by long-term high utilisation levels.
- ZEFER will undertake higher-visibility dissemination work to ensure that the fleet operation use case is expandable across other European regions. Round tables with policymakers and taxi operators will be hosted by the project to increase awareness of the business case for FCEVs in fleet applications.
- Project reports analysing the business case for FCEVs in high-mileage applications will be produced.
- New iterations of the business case and customer acceptance reports are expected.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
FCEVs							
Project's own objectives	Min. distance for vehicles	km/vehicle	90 000	~ 45 500 km per year pre-COVID-19 for certain fleets	⚙️	FCEVs operated as taxis in H2ME drive an average of ~ 45 000 km per year	2020
	Vehicle availability	%	> 98	> 99	✓	> 99	2021
	Range	km	500	650	✓	756	2020
HRSs							
Project's own objectives	HRS availability	%	> 98	> 98	✓	98	2016
	Hydrogen purity	%	99.99	99.99	✓	99.99	2020
	Level of back-to-back vehicle refuelling	refuelling events/h	6	6	✓	6	2020
	Cost of hydrogen	€/kg	≤10	10	✓	10	

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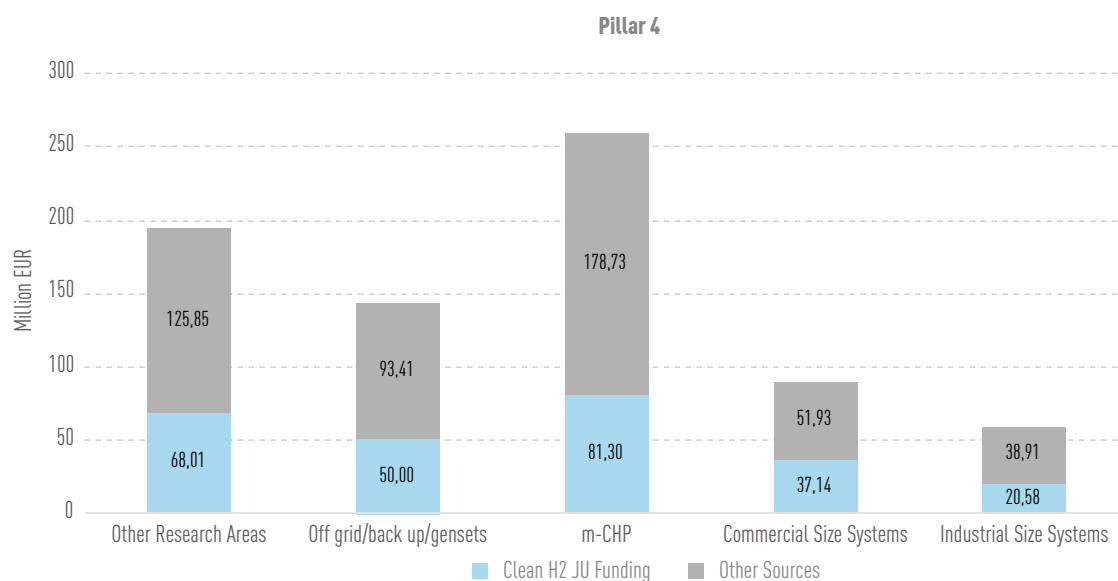
PILLAR 4 - H₂ END USES – CLEAN HEAT AND POWER

Objectives: The overall goal of this Pillar is to support European supply chain actors to develop a portfolio of solutions providing clean, renewable and flexible heat and power generation for all end users' needs and across all system sizes; from domestic systems all the way to large-scale power generation plants. Preferential support will be for solutions running on 100% hydrogen.

Stationary fuel cell systems for power and combined heat and power generation, as well as for provision of back-up power still need additional development and larger production volumes to allow competition of CHP technologies with well-established traditional ones, aiming to reduce investment and operational costs whilst improving system durability.

Budget: The FCH JU funding contribution amounts to about 34% of the total funding for the portfolio of projects considered in this Pillar. A detailed split per research area is presented in Figure 48.

Figure 48: Funding for Pillar 4 projects from 2008 to present.

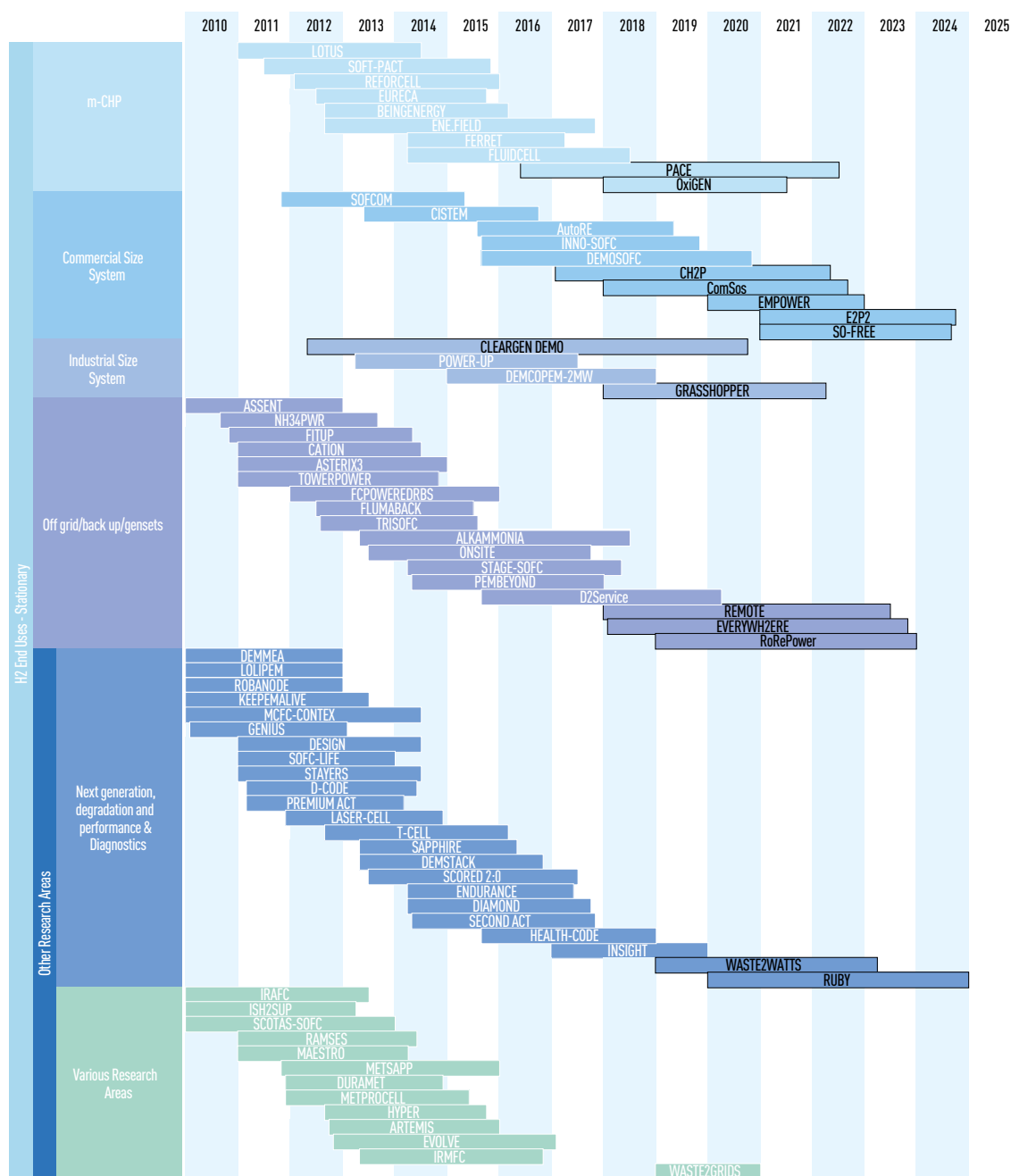


Source: Clean Hydrogen JU

Projects: The Clean Hydrogen JU programme portfolio of stationary fuel cell applications projects as of 2010 is shown in Figure 49. The present review covers the 13 projects emphasised in bold that are still under execution or will be completed in 2022. Additionally, one project, namely CLEARGEN DEMO is considered also in the present review.

Half of the projects – 7 out of 14 - are focused on the use of SOFC technology, 4 projects are addressing PEMFC technology, from which one is dedicated to high temperature PEM technology, one project is looking into both Alkaline and PEMFC and 2 projects are related to both SOFC and PEMFC. The SRIA also includes the new activity area "Gas turbines, boilers and burners", in which currently there are no projects.

Figure 49: Project timelines of Pillar 4 – H₂ End Uses – Clean Heat and Power. Projects highlighted in black were considered for the 2022 Assessment.

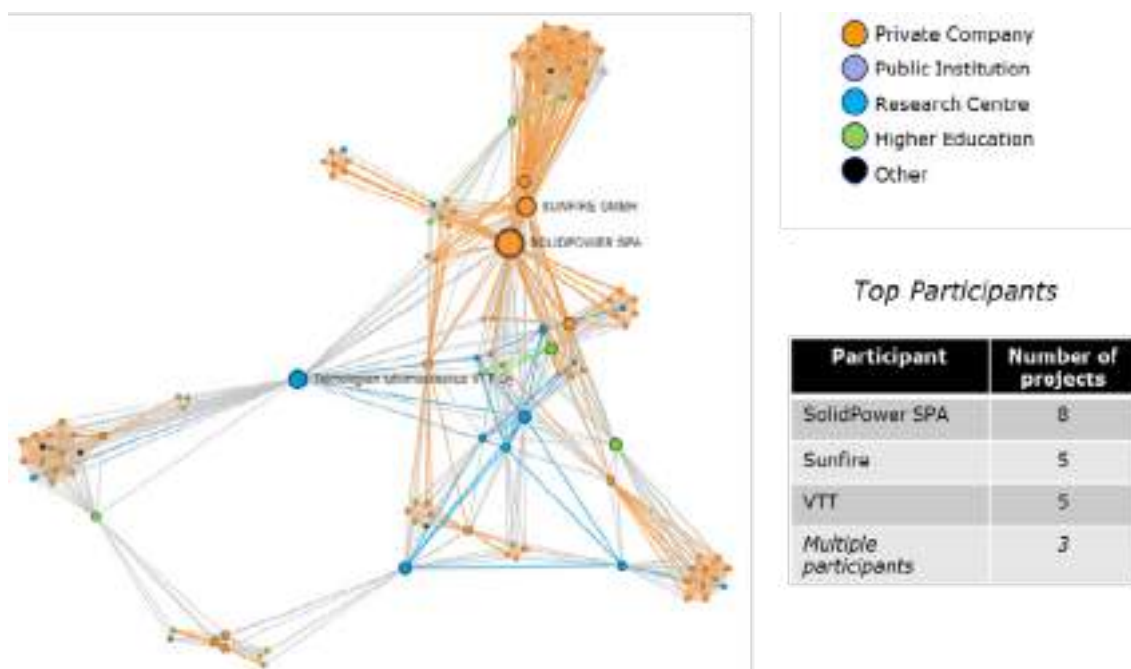


Source: Clean Hydrogen JU

Figure 50 shows that many projects are strongly linked to each other. The key partners present in multiple projects in Pillar 4 are the FC stacks/system providers (Solid Power, Sunfire) and the research institute VTT¹³⁶. Private companies dominate the participants in these projects as a result of being higher TRL demonstration cases.

136. Technical Research Centre of Finland

Figure 50: TIM plot showing country participation in Pillar 4 projects.¹³⁷



Source: TIM (JRC)

MICRO CHP

PACE project is a big deployment initiative engaging six leading European fuel cell manufacturers: Bosch, Solid Power, Viessmann, BDR Thermea, Hexis and Sunfire. PACE is a continuation of ENEFIELD. The project enables manufacturers to move towards product industrialisation and fosters market development at national level by working together with building professionals and the wider energy community. Up to Dec 2021, this project was able to achieve 2,909 units sold and prove that fuel cells can operate seamlessly for a long periods of time (15 years system lifetime with > 50% reduction in stack replacement or no stack replacement during a 10 year service plan). In addition, the manufacturing capacity, for some OEMs, has been proven to reach 2,300 systems/year per OEM, while the target was set at 1,000. These results are excellent in comparison to SoA. At the same time, with a limited number of global fuel cell stack suppliers, the evolving market has resulted in some supply chain challenges. Although the technology is proven and ready for market, there are still a few barriers to uptake by the market, related to the numerous standards in place developed for other technologies that are not all specific to the FC m-CHP technology.

OXIGEN (Next-generation SOFC stack and hot box solution for small stationary applications) aims at developing an innovative SOFC platform, including an all-ceramic stack design and a modular hotbox, for small stationary m-CHP applications. The objectives are to achieve a higher durability and simpler design, which can fulfil the customers' needs for long lifetime, high efficiency and low cost, in m-CHP and other segments. Thorough modelling-based analysis was performed to define the ideal hotbox for single houses, multi-family house and the commercial sector. The major finding was that the optimal hotbox size is strongly correlated to the number of times the system is required to shut down. Even though many challenges could be solved, the co-sintering technology of the stacks is not sufficiently robust yet. In addition the m-CHP may become more relevant and attractive in the future, when house owners will have to charge their electrical vehicles during the night.

137. 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 table insert shows the top 5 countries.

COMMERCIAL SIZE CHP

The key objective of the **ComSos** project is to validate and demonstrate fuel cell based combined heat and power solutions in the mid-sized power ranges of 10-12 kW, 20-25 kW, and 50-60 kW (referred to as Mini FC-CHP). The core of the consortium consists of three SOFC system manufacturers aligned with individual strategies along the value chain: Solid Power, Sunfire and Convion. Despite the accumulated delay in making customer contracts to demonstrate systems, due to Covid and other reasons, the project has made significant progress. Solid Power has contracted 14 BG- 60 units and other 12 units are close to be finalized with customer in 2021. Another OEM (Sunfire) declared not being able to deliver the expected number of units. They will deliver 4 instead of 6 units. Therefore, the total power output capacity of the project is reduced by more than 10% (400 kW against of 450 kW declared in the DoA). All four Sunfire systems have been installed at customer sites in 2021 and will generate 1,000 of hours demonstration data. The first Convion unit has also been installed at the customer site in 2021. In 2022 the second Convion system and the rest of the Solid Power units will be installed at the customer site and start operation. Still, it will be difficult to reach enough long demonstration time (9,000 hours) for all systems during the project duration.

SO-FREE project aims at the development and demonstration of a fully future-ready SOFC based system for CHP generation allowing an operation window from zero to 100% H₂ in natural gas and with additions of purified biogas. Furthermore, SO-FREE will endeavour the realization of a standardized stack-system interface, allowing full interchangeability of SOFC stack types within a given SOFC- CHP system.

The **EMPOWER** project will develop, manufacture and validate a methanol fuelled 5 kWe CHP system based on HT PEMFC technology. The developed CHP unit will be capable of fast start-up and fast dynamic response to help integration of intermittent power production from renewable energy sources. The project contributed to increase visibility and awareness of the potential of renewable methanol. Another overarching achievement of the project is the production of affordable and secure electricity with low carbon footprint; the carbon footprint will be analysed in 2022. The project is interacting and learning from EVERYWH2ERE project.

The **CH2P** project designed, constructed and partially validated an innovative system prototype for hydrogen production. The system co-generates hydrogen, heat and electricity using SOFC technology fueled by carbon lean NG or bio-methane. Thus, with one single technology, CH2P will deliver natural gas, hydrogen and power. CH2P targets six use cases and has the ambition of producing hydrogen at less than 4 €/kg. CH2P prototype will be used to develop the SWITCH system that will integrate the electrolysis mode of operation for green hydrogen production.

INDUSTRIAL SIZE CHP (BEYOND 100 KW)

CLEARGEN DEMO project took over ten years (since mid 2012) and the fuel cell plant is installed and on-site, but is still not in operation. This project consists of two 500kW ClearGen units with PSA purification system, which should have been installed in refinery in Martinique to demonstrate the deployment of fuel cell megawatt scale power system at a European chemical production plant.

The **GRASSHOPPER** project aims to create a next-generation MW-size fuel cell power plant, which is more cost-effective and flexible in power output. The plant will be demonstrated in the field as a 100 kW sub-module pilot plant, implementing newly developed BoP system components and stacks. The plant must be fed directly with H₂ provided by a chloralkali plant. The pilot plant must provide a flexible power service with a variable output to match the grid necessities. The project delayed because the site demonstration location had to change, caused by change of the owner of the installation, in which the system would be installed.

OFF GRID / BACK UP / GENSETS

REMOTE project is demonstrating the technical and economic feasibility of H₂ based energy storage solutions (integrated P2P, non-integrated P2G+G2P, customized P2P systems), deployed in 3 demos, based on RES energy

inputs (solar, wind, hydro) in isolated micro-grid or off grid remote areas. In its 4th year (December 2021), the design, procurement, installation, operation, analysis of 2 demos (in Norway and Greece) have been assessed, while the third demo (in Spain) is under installation. Operation is planned to start in 2022.

The overall objective of **RoRePower** project is to further develop and demonstrate SOFC 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) as well as, and the power supply of telecommunication towers especially in emerging countries. One of the project's major achievements is the installation of 21 RoRePower units at the customer sites, that will give a demonstration data in 2022 (12 units were already installed during the previous reporting period). The project plans to install 31 units in total. Harsh condition operation have been reached: The Sunfire FC has operated at -20°C with NG and at -35°C with Propane; The Solid Power FC has operated at -20 °C with NG. Maintenance frequency is now lower (13.7 months) than the AWP target (15 months) but very close to that; the goal is to reach it before the end of the project.

EVERYWH2ERE project will integrate already demonstrated robust PEMFC stacks and low weight intrinsically safe pressurized hydrogen technologies into easy to install, easy to transport FC based transportable gensets. The project finalised so far two of the prototypes "plug and play" gensets (1x25 kW and 1x100 kW), together with the related hydrogen storage bundles. Progress was also done towards standardisation of the products - declaration of conformity of 100 kW was finalized and for the 25 kW FC is on-going. Port of Tenerife will host the 100 kW genset for demonstration. Potentially the project results can be used also in new fields – in the context of off-grid and integrated with hydrogen production (electrolyser).

OTHER RESEARCH AREAS

WASTE2WATTS is designing an integrated SOFC CHP system fed with biogas using innovative purification solutions. Solutions for small-scale units (5-50 kWe) will be based on a solid sorbent matrix; while for medium-to-large scale units (≥ 500 kWe) a novel cooling approach to purification is pursued. The aim of the project is to perform a test campaign using representative test gases with viable reforming catalysts and SOFC stacks, supplied by Solid Power and Sunfire. Major project achievements consist of the characterisation of sorbents specifically for biogas cleaning, allowing the choice of an adapted cleaning solution, reformer catalysts, cells and stacks as well as system cost analysis. The system cost analysis shows that biogas-SOFC can achieve levelised cost of electricity < 15 ct€/kWh even at 20 kWe, for 4 year stack life (stack cost 1000 €/kWe). SOFCs can use the biogas niche market, equipped with proper gas cleaning. 6 kWe prototype test is being prepared.

The **RUBY** project aims at exploiting Electrochemical Impedance Spectroscopy (EIS) for developing, integrating, engineering, and testing a comprehensive and generalized Monitoring, Diagnostic, Prognostic and Control (MDPC) tool. The project had to suspend its activities between June - October 2021 to allow the reorganisation of the consortium. One key partner (Solid Power) left mid 2021 and was replaced by Sunfire in November 2021.

CH2P

COGENERATION OF HYDROGEN AND POWER USING SOLID OXIDE BASED SYSTEM FED BY METHANE RICH GAS

Project ID	735692
PRD 2022 Panel	4 – End use: Stationary applications
Call topic	FCH-02-4-2016: Cogeneration of hydrogen and electricity with high-temperature fuel cells
Project total costs	EUR 6 711 722.58
Clean H ₂ max. contribution	EUR 3 999 896
Project period	1/2/2017 – 30/4/2022
Coordinator	Fondazione Bruno Kessler, Italy
Beneficiaries	HyGear Operations BV, HyGear Technology and Services BV, Vertech Group, SOLIDpower SpA, SOLIDpower SA, HyGear Fuel Cell Systems BV, HyGear BV, Shell Global Solutions International BV, École Polytechnique Fédérale de Lausanne, Deutsches Zentrum für Luft- und Raumfahrt EV

<https://ch2p.eu>

PROJECT AND OBJECTIVES

The CH2P project is designing, constructing and partially validating an innovative system prototype for hydrogen production. The system co-generates hydrogen, heat and electricity using solid oxide cell technology fuelled by carbon-lean natural gas (NG) or biomethane. The CH2P system operates in five modes, allowing flexibility in hydrogen and electricity supply. The prototype is placed in two 40-foot containers and it is modular to support future upscaling. CH2P has been designed as a transition technology for application at hydrogen-refuelling stations and has the ambition of producing hydrogen at < 4 €/kg.

NON-QUANTITATIVE OBJECTIVES

- CH2P targets 6 use cases.
- The project aims to co-generate hydrogen and electricity for hydrogen-refuelling stations. With a single technology, CH2P will deliver natural gas, hydrogen and power – the fuels of the EU directive on alternative fuels infrastructure.

PROGRESS AND MAIN ACHIEVEMENTS

- The large stack module has been built.
- CH2P created a pressure swing absorber.
- The project created a customised hot balance of plant.

FUTURE STEPS AND PLANS

- The CH2P system will run through the final testing phase, which is due to start shortly.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
AWP 2016	System size	kg of H ₂ /day	20	16	⚙️
	Flexible cogeneration of H ₂ and power	%	50 + 50	90	⚙️
	System efficiency	%	65	80	✓

COMSOS

COMMERCIAL-SCALE SOFC SYSTEMS



Project ID	779481
PRD 2022 Panel	4 – End use: Stationary applications
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 costs	EUR 10 277 897.50
Clean H ₂ max. contribution	EUR 7 486 954.75
Project period	1/1/2018 – 31/8/2022
Coordinator	Teknologian tutkimuskeskus VTT Oy, Finland
Beneficiaries	Energy Matters BV, Convion Oy, Sunfire GmbH, SOLIDpower SpA, SOLIDpower SA, Politecnico di Torino
http://www.comsos.eu/	

PROJECT AND OBJECTIVES

The key objective of the ComSOS project is to validate and demonstrate fuel-cell-based combined heat and power solutions in the mid-sized power ranges of 10–12 kW, 20–25 kW and 50–60 kW (referred to as Mini FC-CHP). The core of the project consortium consists of three SOFC system manufacturers aligned with individual strategies along the value chain: SOLIDpower, SunFire and Convion.

PROGRESS AND MAIN ACHIEVEMENTS

- All four Sunfire systems have been installed at customer sites.
- The first Convion unit has been installed at

the customer site.

- SOLIDpower has contracted 14 BG-60 units and a further 12 units are close to being finalised.

FUTURE STEPS AND PLANS

- The second Convion unit will be installed at the customer site and start operation in 2022.
- The rest of the SOLIDpower units will be installed at customer sites and start operation in 2022.
- All four Sunfire units are expected to generate 1 000 hours of demonstration data in 2022.



QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objective	SME participation	%	25	50	✓
MAWP Addendum (2018–2020)	NOx emission	mg/kWh	< 40	< 40	✓
	Electrical efficiency	%	> 50	> 50	✓

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E2P2

ECO EDGE PRIME POWER



Project ID	101007219
PRD 2022 Panel	4 – End use: Stationary applications
Call topic	FCH-02-9-2020: Fuel cell for prime power in data-centres
Project total costs	EUR 3 576 995.38
Clean H ₂ max. contribution	EUR 2 499 715.50
Project period	1/1/2021 – 31/9/2024
Coordinator	Research Institutes of Sweden AB, Sweden
Beneficiaries	Vertiv Croatia DOO za trgovinu i usluge, Vertiv, InfraPrime GmbH, Equinix Netherlands BV, Snam SpA, TEC4FUELS, SOLIDpower SpA
http://www.e2p2.eu/	

PROJECT AND OBJECTIVES

The main objectives of E2P2 are to define the fuel cell prime power concept for data centres and create an authoritative open standard for fuel cell adaptation 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 the European fuel cell suppliers to increase their uptake across multiple markets, with improved energy efficiency and cost-effectiveness.

PROGRESS AND MAIN ACHIEVEMENTS

The project started in 2021.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
	Electrical efficiency	% LHV	42–62		
MAWP (2014–2020)	Availability (% of plant's available power)	%	97	N/A	
	CAPEX	€/kW	3 500–6 500		

EMPOWER

EUROPEAN METHANOL POWERED FUEL CELL CHP

Project ID	875081
PRD 2022 Panel	4 – End use: Stationary applications
Call topic	FCH-02-7-2019: Development of highly efficient and flexible mini CHP fuel cell system based on HTPMFCs
Project total costs	EUR 1 499 876.25
Clean H ₂ max. contribution	EUR 1 499 876.25
Project period	1/1/2020 – 31/12/2022
Coordinator	Teknologian tutkimuskeskus VTT Oy, Finland
Beneficiaries	Blue World Technologies ApS, THT Control Oy, Catator AB, Universidade do Porto

<http://www.empower-euproject.eu/>

PROJECT AND OBJECTIVES

The project will develop, manufacture and validate a methanol-fuelled 5 kWe combined heat and power (CHP) system based on high-temperature proton-exchange membrane fuel cell (HT-PEMFC) technology. The project will enhance the system's efficiency to target the mini-CHP market and provide a cost-competitive and low-carbon option. The developed CHP unit will be capable of fast start-up and fast dynamic response to help the integration of intermittent power production from renewable energy sources. Currently, the subsystems of the CHP are being finalised by project partners. The integration of the final CHP system has started.

NON-QUANTITATIVE OBJECTIVES

- EMPOWER aims to increase the visibility and awareness of the potential of renewable methanol. The project results are being openly communicated and disseminated, for example through public deliverables and scientific publications. The project has also arranged an international summer school on hydrogen technologies.
- The project aims to develop a business analysis for the use of renewable methanol in CHPs and other applications. Preliminary market analysis was performed in 2021, and this will be updated at the end of the project.
- EMPOWER aims to support knowledge exchange and production ramp-up through stakeholder searching, information and link-

age. An industry webinar was arranged in January 2021, a workshop was arranged in Denmark in May 2022 and another is planned in Finland in December 2022.

- The main goal of the project is to produce affordable and secure electricity with a low carbon footprint. The carbon footprint will be analysed in 2022.

PROGRESS AND MAIN ACHIEVEMENTS

- The HT-PEMFC stack has been designed for pressurised operation.
- The CHP system enclosure and system balance-of-plant components have been finalised.
- The automated quality control methods for stack components have been developed.

FUTURE STEPS AND PLANS

- EMPOWER will demonstrate the project's 5 kW HT-PEMFC CHP system in the relevant end-user environment. The designed system will be demonstrated in autumn/winter 2022 in Finland to evaluate its performance and the project's key performance indicators.
- The HT-PEMFC subsystem will be integrated into the CHP system (planned for spring 2022).
- The system scale-up study (50–100 kW), carbon footprint analysis and business analysis will be performed in 2022.
- Scientific studies on aqueous-phase-reforming catalysts will be finalised during 2022.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objectives	Rated stack electrical efficiency (LHV reformat gas)	%	55	N/A	⚙️
	Fuel processing efficiency	%	85	> 85	✓
MAWP Addendum (2018–2020)	CHP electrical efficiency (LHV methanol)	%	37–67	N/A	⚙️
	CAPEX	€/kWh	5 500	2 600	✓

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EVERYWH₂ERE

MAKING HYDROGEN AFFORDABLE TO SUSTAINABLY
OPERATE EVERYWHERE IN EUROPEAN CITIES

Project ID	779606
PRD 2022 Panel	4 – End use: Stationary applications
Call topic	FCH-02-10-2017: Transportable FC gensets for temporary power supply in urban applications
Project total costs	EUR 6 770 248.74
Clean H ₂ max. contribution	EUR 4 999 945.76
Project period	1/2/2018 – 31/10/2023
Coordinator	RINA Consulting SpA, Italy
Beneficiaries	FRIEM SpA, Linde Gas Italia SRL, Delta1 gUG (Haftungsbeschränkt), Swiss Hydrogen SA, Teknologian tutkimuskeskus VTT Oy, Mahytec SARL, Iren Smart Solutions SpA, Iren Energia SpA, Iren SpA, Genport SRL – spin off del Politecnico di Milano, THT Control Oy, PowerCell Sweden AB, Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón, ICLEI Europasekretariat GmbH, Parco Scientifico Tecnologico per l'Ambiente Environment Park Torino SpA, Acciona Construcción SA

<http://www.everywh2ere.eu/>

PROJECT AND OBJECTIVES

The EVERYWH₂ERE project will integrate 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. Eight fuel cell 'plug and play' gensets fitted in containers will be realised and tested through a pan-European demonstration campaign in a demonstration-to-market approach. The prototypes will be tested at construction sites, music festivals and urban public events all around Europe, demonstrating their flexibility and their increased lifetimes.

NON-QUANTITATIVE OBJECTIVES

EVERYWH₂ERE aims to support the development of a regulatory framework for transportable hydrogen-fuelled systems.

PROGRESS AND MAIN ACHIEVEMENTS

- EVERYWH₂ERE organised a meeting with user communities. This involved interaction with rental companies and energy companies promoting use of fuel-cell-based gensets to their customers.
- The project undertook IPR activities to understand partners' exploitation intentions and potential common interests.
- EVERYWH₂ERE took steps towards standardisation. The assessment of the conformity of the 100 kW genset has been completed, whereas that of the 25 kW genset is ongoing.

FUTURE STEPS AND PLANS

- The project will finalise the commissioning of the first two prototypes and start demonstration (demonstration started on 1 June 2021). Prototypes are ready and validation is ongoing; this was being remotely supported owing to the travel ban for partners' staff due to COVID-19. The project will realise the other gensets. The finalisation of the commissioning is to be complete by the end of 2022.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
Project's own objectives	Levelised cost of energy of the genset (identification of replication market with contractual costs \pm 10 % of those of current power supply solutions)	€/kWh	1.1	N/A	⚙️	1 €/kWh for diesel gensets according to rental market stakeholders. According to LCC, the current €/kWh is very close to 1.10: this value has to be validated and evaluated for contractual/business purposes	2025
	Noise emission (of the full genset, not only the FC SuSy)	dB	< 65	60	✓	Diesel gensets insulated if very noisy (first tests guarantee operation at < 60 dB), mostly due to the fan of the FC thermal loop	2020
	Future manufacturing CAPEX (of the system)	€/kW	5 500	6 850	⚙️	No FC-based gensets available today (according to stakeholders, 1 500–2 000 €/kW may be acceptable)	2025

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GRASSHOPPER

GRID ASSISTING MODULAR HYDROGEN PEM POWER PLANT



Project ID	779430
PRD 2022 Panel	4 – End use: Stationary applications
Call topic	FCH-02-7-2017: Development of flexible large fuel cell power plants for grid support
Project total costs	EUR 4 387 063.75
Clean H ₂ max. contribution	EUR 4 387 063.75
Project period	1/1/2018 – 31/3/2022
Coordinator	Informatizacija Energetika Avtomatizacija DOO, Slovenia
Beneficiaries	Johnson Matthey Fuel Cells Limited, Zentrum für Brennstoffzellen- Technik GmbH, Abengoa Innovacion Sociedad Anonima, Nedstack Fuel Cell Technology BV, Politecnico di Milano

<http://www.grasshopperproject.eu/>

PROJECT AND OBJECTIVES

The GRASSHOPPER project aims to create a next-generation MW-sized fuel cell power plant that (FCPP) is more cost-effective and flexible in power output than current fuel cell power plants. The FCPP will be demonstrated in the field as a 100 kW submodule pilot plant, implementing newly developed balance-of-plant system components and stacks. A new stack design has been developed with increased power density, and short stack testing has been concluded. The pilot plant is undergoing factory acceptance testing on hydrogen. A dynamic simulation model of the pilot plant has been developed to support optimisation in the field and the scaling up of the design.

NON-QUANTITATIVE OBJECTIVES

The project aims to ensure operation flexibility and grid stabilisation capability via fast

response. The operation strategy was defined considering the requirements in terms of response time for grid stabilisation.

PROGRESS AND MAIN ACHIEVEMENTS

- GRASSHOPPER has developed a new pilot power plant.
- It has developed a new fuel cell.
- The GRASSHOPPER membrane electrode assemblies (MEAs) show excellent durability in accelerated stress testing.

FUTURE STEPS AND PLANS

- The project will perform the testing, relocation and start-up of the pilot plant. Factory acceptance testing is ongoing. Once the site has been constructed, the plant will be relocated to the site.
- It will assemble the full stacks for the 100 kW plant. This will involve component optimisation on cell plates for the full stack.



QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
Project's own objectives	MEA cost reduction	%	65		MEA cost of electricity = 0.04 €/kWh	
	Stack efficiency	%	55		55	
MAWP Addendum (2018–2020)	System electrical efficiency	%	50		50	2018
	System CAPEX	€/kWe	1 500		3 000	
AWP 2017	Stack lifetime	hours	20 000		16 000	

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OXIGEN

NEXT-GENERATION SOLID OXIDE FUEL CELL STACK AND HOT BOX SOLUTION FOR SMALL STATIONARY APPLICATIONS



Project ID	779537
PRD 2022 Panel	4 – End use: Stationary applications
Call topic	FCH-02-9-2017: Development of next-generation SOFC stack for small stationary applications
Project total costs	EUR 2 996 873.75
Clean H ₂ max. contribution	EUR 2 996 873.75
Project period	1/1/2018 – 30/6/2021
Coordinator	Société européenne des produits réfractaires, France
Beneficiaries	Sintef AS, Saint-Gobain Centre de Recherches et d'Etudes Europeen, Europäisches Institut Für Energieforschung EDF – KIT EWIV, ICI Caldaie SpA, Saint-Gobain Recherche SA, ENGIE, Stiftelsen Sintef, Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung EV, Commissariat à l'énergie atomique et aux énergies alternatives

<http://oxigen-fch-project.eu/>

PROJECT AND OBJECTIVES

OxiGEN aims to develop an innovative solid oxide fuel cell platform, including an all-ceramic stack design and a modular hot box, for small stationary micro-combined-heat-and-power (micro-CHP) applications. The objectives are to achieve a higher level of durability and a simpler design in micro-CHP units and other segments to fulfil customers' needs for long product lifetimes, high efficiency and low costs. Such a system will reduce the lifetime CO₂ emissions for a combined heating and electricity-generation system and reduce the financial burden for customers (individual property owners or small businesses).

NON-QUANTITATIVE OBJECTIVES

- OxiGEN aims to define market specifications for residential and small commercial applications, and the boundary limits of the

hot box (completed).

- The project aims to produce a stack design (completed).
- It aims to produce a hot box design (completed).
- OxiGEN aims to produce the Gen3 short stack (in progress).

PROGRESS AND MAIN ACHIEVEMENTS

- OxiGEN has produced hot box specifications.
- It has produced a hot box for the Saint-Gobain stack.
- The project has developed a novel electrolyte composition with improved conductivity.

FUTURE STEPS AND PLANS

The project has finished.



PACE

PATHWAY TO A COMPETITIVE EUROPEAN FC MCHP MARKET



Project ID	700339
PRD 2022 Panel	4 – End use: Stationary applications
Call topic	FCH-02.9-2015: Large scale demonstration μ CHP fuel cells
Project total costs	EUR 84 462 140.62
Clean H ₂ max. contribution	EUR 33 932 752.75
Project period	1/6/2016 – 30/6/2022
Coordinator	European Association for the Promotion of Cogeneration VZW, Belgium
Beneficiaries	Element Energy, Remeha GmbH, Remeha NV, Viessmann Elektronik GmbH, Viessmann Werke Allendorf GmbH, BDR Thermea Group BV, SOLIDpower GmbH, Sunfire Fuel Cells GmbH, Remeha BV, Viessmann Werke GmbH & Co. KG, Sunfire GmbH, Baxi Innotech GmbH, Bosch Thermotechnik GmbH, SOLIDpower SpA, SenerTec Kraft-Wärme-Energiesysteme GmbH, EWE Aktiengesellschaft, Vaillant GmbH, Element Energy Limited, Hexis AG, Fachhochschule Zentralschweiz – Hochschule Luzern, Danmarks Tekniske Universitet

<http://www.pace-energy.eu/>

PROJECT AND OBJECTIVES

PACE is unlocking the large-scale European deployment of the state-of-the-art smart energy solution for private homes: fuel cell micro-cogeneration. PACE will see up to 2 800 households across Europe reaping the benefits of this home energy system. The project enables manufacturers to move towards product industrialisation and fosters market development at national level by working together with building professionals and the wider energy community. The project uses modern fuel cell technology to produce efficient heat and electricity at home, empowering consumers in their energy choices.

NON-QUANTITATIVE OBJECTIVES

- The project aims to achieve a system (excluding stack) lifetime of 10 years.
- It is planned that the need for stack replacement will be eliminated for all partners within the next 7 years.

PROGRESS AND MAIN ACHIEVEMENTS

- A total of 2 121 units have been commissioned to date.
- The project has increased the system lifetime to more than 15 years and improved the

maintenance interval using new/improved components. The system (excluding stack) lifetime was 10 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 will eliminate 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

- All of the 2 800 units to be deployed in the project will be installed.
- PACE will continue data collection and analysis to provide a fact-based understanding of the performance and benefits of technology.
- The project will identify ongoing regulatory barriers to the deployment of micro-combined-heat-and-power (micro-CHP) units across Europe, and collaborate with industry and policymakers to remove barriers.
- The project will develop use cases for fuel cell micro-CHP units relevant beyond the project finish point, including an assessment of the economic potential of fuel cell micro-CHP units.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
	Number of units sold	pieces	2 800	2 909	✓
Project's own objectives	Time before stack replacement	years	10 years' system lifetime with > 50 % reduction in stack replacement or no stack replacement during a 10-year service plan	15 years' system lifetime with > 50 % reduction in stack replacement or no stack replacement during a 10-year service plan	✓
	Manufacturing capacity (average production level)	pieces/year	1 000	2 300	✓

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REMOTE

REMOTE AREA ENERGY SUPPLY WITH MULTIPLE OPTIONS FOR INTEGRATED HYDROGEN-BASED TECHNOLOGIES

Project ID	779541
PRD 2022 Panel	4 – End use: Stationary applications
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 costs	EUR 6 740 031.40
Clean H ₂ max. contribution	EUR 4 995 950.25
Project period	1/1/2018 – 30/6/2023
Coordinator	Politecnico di Torino, Italy
Beneficiaries	Grupo Capisa Gestion y Servicios Sociedad Limitada, Sintef AS, Engie EPS Italia SRL, Trønderenergi AS, Orizwn Anonymh Techniki Etaireia, Powidian, IRIS SRL, Hydrogenics Europe NV, Instrumentación y Componentes SA, Enel Green Power SpA, Ballard Power Systems Europe AS, Ethniko Kentro Erevnas kai Technologikis Anaptyxis, Instituto Tecnológico De Canarias SA, Stiftelsen Sintef

<http://www.remote-euproject.eu/>

PROJECT AND OBJECTIVES

REMOTE is demonstrating the technical and economic feasibility of H₂-based energy storage solutions (integrated power-to-power (P2P) systems, non-integrated power-to-gas and gas-to-power systems (P2G+G2P), customised P2P systems) deployed in 3 demonstrations, based on renewable energy source (RES) inputs (solar, wind, hydro) in isolated microgrid or off-grid remote areas. In the 4 years of the project (up to December 2021), the design, procurement, installation, operation and analysis of 2 demonstrations (in Greece and Norway) have been assessed; the third demonstration (in Spain) is being finalised. The demonstration analysis is being carried out, and the exploitation plans are under development.

NON-QUANTITATIVE OBJECTIVES

- REMOTE aims to complete the demonstrations' design, installation and operation. REMOTE has created fundamental know-how for the next generation of P2Ps based on fuel cells and H₂ 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 enables 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 H₂-based devices (PEMFC, electrolyzers) 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 electrolyzers in P2P applications. Companies now know what to improve.

- The project aimed to complete detailed life cycle analysis of RES-fed, H₂-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 H₂ at a local RES-storage system at seasonal range.

PROGRESS AND MAIN ACHIEVEMENTS

- REMOTE has achieved 1 year of experience of operation of the demonstration in Norway.
- It has achieved 1.5 years of experience of operation of the demonstration in Greece.
- The project has complete experience of the design, commissioning and operation of H₂-based P2P plants.

FUTURE STEPS AND PLANS

- The running and full analysis of the demonstration in Norway have been completed. The collected data are undergoing deep technical analysis.
- The running and full analysis of the demonstration in Greece have been completed. The collected data are undergoing deep technical analysis.
- REMOTE will finalise the installation of the new demonstration in Spain, and then put it in operation. The demonstration is under construction. The demonstration has been fully operational since July 2022, and is ready for data collection and analysis.
- Complete techno-economic analysis of the demonstration experience will be 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 H₂-based P2P plants for remote locations will be developed and presented to the market stakeholders.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
MAWP Addendum (2018–2020)	Rated efficiency of the 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 the fuel cell (PEM)	% LVH	42–62 (2024)	45–55	✓	51	2018
	Rated efficiency of the electrolyser (alkaline)	kWh/kg	50 (2020) 49 (2024)	55–60	⚙️	55–60	2020

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ROREPOWER

ROBUST AND REMOTE POWER SUPPLY

Project ID	824953
PRD 2022 Panel	4 – End use: Stationary applications
Call topic	FCH-02-3-2018: Robust, efficient long term remote power supply
Project total costs	EUR 4 220 093.75
Clean H ₂ 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, Sunfire Fuel Cells GmbH, Sunfire GmbH, SOLIDpower SpA, European Fuel Cell Forum AG

<https://rorepower.com>

PROJECT AND OBJECTIVES

The overall objective of this project is to further develop and demonstrate solid oxide fuel cell (SOFC) systems for off-grid power generation in markets – such as the oil and gas infrastructure in remote regions – with harsh climate conditions (from – 40 °C to 50 °C), and the power supply of telecommunication towers, especially in emerging countries (e.g. telecommunication base stations or microwave transceivers). To date, 31 units have been installed at customer sites or are in the process of being installed. RoRePower is further strengthening and building the European value chain for fuel cell technologies.

PROGRESS AND MAIN ACHIEVEMENTS

- A total of 21 RoRePower units had been installed at the customer sites by the end

of 2021.

- Harsh condition operation has been achieved: Sunfire Fuel Cells has operated at – 20 °C with natural gas and at – 35 °C with propane; SOLIDpower has operated at – 20 °C with natural gas.

FUTURE STEPS AND PLANS

- All RoRePower units will be installed at customer sites. In total, 31 customer contracts for demonstration sites have been signed; for 21 of these, units have already been installed.
- All RoRePower units have been demonstrated for a sufficiently long time. In total, 21 units will provide demonstration data in 2022.



QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
AWP 2019 annual work plan	Electrical efficiency	%	> 35	> 35	✓
	Operation in harsh conditions	°C	– 40	– 40 can be achieved with the project solutions	✓
	Maintenance frequency	months	15	13.7	✓
	Long-term desulphurisation	months	15	15	✓
	System start-up in harsh conditions	°C	– 40	– 40 can be achieved with the project solutions	✓

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RUBY

ROBUST AND RELIABLE GENERAL MANAGEMENT TOOL FOR PERFORMANCE AND DURABILITY IMPROVEMENT OF FUEL CELL STATIONARY UNITS



Project ID	875047
PRD 2022 Panel	4 – End use: Stationary applications
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 costs	EUR 2 999 715
Clean H ₂ max. contribution	EUR 2 999 715
Project period	1/1/2020 – 31/12/2024
Coordinator	Università degli Studi di Salerno, Italy
Beneficiaries	Communauté d'universités et d'établissements université Bourgogne-Franche-Comté, Sunfire Fuel Cells GmbH, Teknologian tutkimuskeskus VTT Oy, SOLIDpower SpA, Bitron SpA, Ballard Power Systems Europe AS, Europäisches Institut für Energieforschung EDF – KIT EWIV, Fondazione Bruno Kessler, Université De Franche-Comté, Institut 'Jožef Stefan', École Polytechnique Fédérale de Lausanne, Commissariat à l'énergie atomique et aux énergies alternatives
http://www.rubyproject.eu/	

PROJECT AND 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 features, RUBY will improve the efficiency, reliability and durability of solid oxide fuel cell (SOFC) and polymer electrolyte fuel cell (PEMFC) 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 the relevant operational environment.

NON-QUANTITATIVE OBJECTIVES

The MDPC tool performs monitoring, diagnosis, prognosis control and mitigation of the stack and balance of plant (BoP) for PEMFC in back-up applications and for SOFC for micro-

combined-heat-and-power (micro-CHP) applications.


PROGRESS AND MAIN ACHIEVEMENTS

- RUBY has developed the MDPC tool.
- It has produced the hardware configuration.

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 activities. The tool monitors the state of health of the stacks and the systems, detects faults at stack and balance-of-plant levels, estimates the stacks' lifetimes, applies advanced control actions and proposes mitigation strategies at system level.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
Project's own objectives	Lifetime of micro-CHP applications (SOFC)	years	12	10		10	2020
		% of the appliance	99	97		97	
	Lifetime of back-up applications (PEMFC)	years	15	12		12	
		% of the appliance	99.999	99.99		99.99	

SO-FREE

SOLID OXIDE FUEL CELL COMBINED HEAT AND POWER: FUTURE-READY ENERGY



Project ID	101006667
PRD 2022 Panel	4 – End use: Stationary applications
Call topic	FCH-02-4-2020: Flexi-fuel stationary SOFC
Project total costs	EUR 3 045 355
Clean H ₂ max. contribution	EUR 2 739 094
Project period	1/1/2021 – 31/8/2024
Coordinator	Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile, Italy
Beneficiaries	Kiwa Limited, Elcogen Oy, Kiwa Nederland BV, Università degli Studi Guglielmo Marconi – Telematica, PGE Polska Grupa Energetyczna SA, ICI Caldaie SpA, Instytut Energetyki, AVL List GmbH, Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung EV

<http://www.so-free.eu/>

PROJECT AND OBJECTIVES

The development and demonstration of a fully future-ready solid oxide fuel cell (SOFC)-based system for combined heat and power (CHP) generation allows for an operation window of 0–100 % of H₂ in natural gas, with additions of purified biogas. Furthermore, SO-FREE will endeavour to realise a standardised stack–system interface, allowing full interchangeability of SOFC stack types within a given SOFC CHP system.

NON-QUANTITATIVE OBJECTIVES

SO-FREE aims to realise a unique, standardised stack module–system interface for flexible system integration. The first alignment of two stack modules with a single interface has been proposed.

PROGRESS AND MAIN ACHIEVEMENTS

- The project has made two identical test stations for independent stack validation.
- SO-FREE has designed a unique stack module–system interface for flexible system integration.

FUTURE STEPS AND PLANS

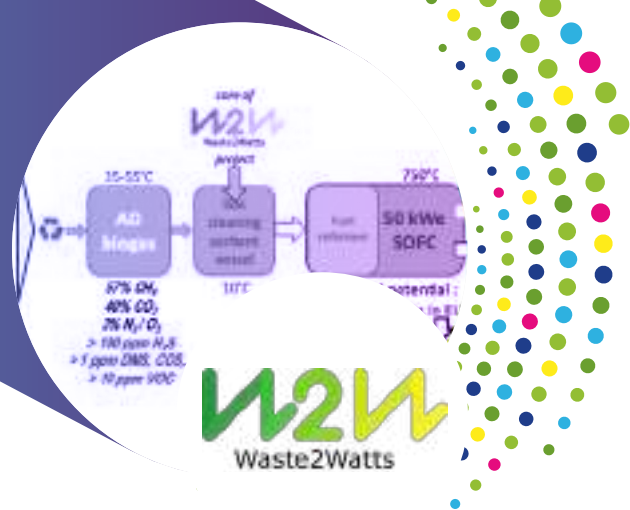
- Stack validation and mapping is expected to start in August 2022.
- The final design of the system is due to be completed in August 2022.
- Stack production and delivery are expected to commence in March 2023.
- Two systems are ready for demonstration until June 2023.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Target achieved?	SoA result achieved to date (by others)
	Degradation rate	%	< 1		0.6
AWP 2020	Efficiency in H ₂ consumption	%	48		47
	CAPEX	€/kW	8 000		10 000

WASTE2WATTS

UNLOCKING UNUSED BIO-WASTE RESOURCES WITH
LOW COST CLEANING AND THERMAL INTEGRATION
WITH SOLID OXIDE FUEL CELLS



Project ID	826234
PRD 2022 Panel	4 – End use: Stationary applications
Call topic	FCH-02-7-2018: Efficient and cost-optimised biogas-based co-generation by high temperature fuel cells
Project total costs	EUR 1 681 602.50
Clean H ₂ max. contribution	EUR 1 681 602.50
Project period	1/1/2019 – 31/3/2023
Coordinator	École Polytechnique Fédérale de Lausanne, Switzerland
Beneficiaries	Etudes et Applications d'Energies Renouvelables et d'Epuración Biokomp SRL, Arol Energy, Sunfire GmbH, SOLIDpower SpA, SOLIDpower SA, Politecnico di Torino, Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile, Commissariat à l'énergie atomique et aux énergies alternatives, Paul Scherrer Institut
https://waste2watts-project.net/	

PROJECT AND OBJECTIVES

WASTE2WATTS is developing cleaning technologies for biogas to make the gas compatible with solid oxide fuel cells (SOFCs). It determines what needs to be cleaned from the gas and to which purity level to clean it. 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 6 kWe SOFC on agro-biogas has been prepared, and novel cryogenic cleaning of biogas at a scale of 100 m³/h has been carried out.

NON-QUANTITATIVE OBJECTIVES

- There is a huge biogas resource in agriculture in Europe for use by small-scale SOFCs (50 kWe, 0.5 million units or 25 GWe; 1 500 PJ = 8 % of the EU's natural gas).
- The project aims to compile the sorbents database. Commercial sorbents have been sourced and characterised.
- It aims to analyse sorbents' real behaviour in relation to specific contaminants. The results of these tests are very different to what has been announced. COS is the most critical contaminant (< 1 g captured per kg of sorbent). It has a strong dependence on gas matrix (O₂, H₂O).
- WASTE2WATTS aims to analyse the behaviour of COS in SOFC cells. The outlet gases are H₂S and SO₂, alternating over time; the water–gas shift reaction is affected.
- The project aims to test new catalysts for biogas reforming (Ni₄Fe, Ru-doped SmCeCoOx). Ru-doped CaZrO₃ with dry reforming, mixed reforming and S-contaminants will be tested.

- WASTE2WATTS aims to perform multicontaminants testing. H₂S, COS, DMS and CH₄S are to be tested simultaneously on sorbents and cells to evaluate the matrix effect.

PROGRESS AND MAIN ACHIEVEMENTS

- Sorbents have been characterised specifically for biogas cleaning, allowing for the choice of an adapted cleaning solution.
- Reformer catalysts, cells and stacks characterised with specific sulphur compounds show resilience of up to 5 ppm of trace content.
- System cost analysis shows that biogas SOFC can achieve a levelised cost of electricity of < 15 ct€/kWe, even at 20 kWe, for a 4-year stack life (stack cost 1 000€/kWe).

FUTURE STEPS AND PLANS

- WASTE2WATTS will install a cryogenic cleaning chain for biogas flow of 100 m³/g on a real biogas site. This will involve ordering components, finalising the piping and instrumentation diagram, and calculations.
- The project will install the 6 kWe SOFC at the agro-biogas site, with adapted biogas cleaning based on project sorbent results. This will involve looking for co-financing, preparing analysis of the site's biogas and preparing a site visit for connections.
- Long-term testing of cells and stacks will be performed with 3–5 ppm of sulphur. All set-ups, gas analytics and detailed electrochemical characterisation methods have been established.
- The project will perform a total system cost calculation with updated input from project results, especially the cleaning (sorbents choice). The system model and cost calculation have been established.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	SoA result achieved to date (by others)	Year of SoA target
MAWP Addendum (2018–2020)	SOFC CAPEX	€/kWe	3 500–6 500 (2024)	2 000–4 000	2 000	2024
Project's own objectives	Pollutant balance	ppm	5	3	5	2021
	Pollutant nature and mix	S-compounds	Identification	Critical compounds identified	N/A	2008
	Biogas cleaning	€/kWe	< 1 000	< 1 000	1 000	2018
	LCOE	€/kWe	< 15	0.09	0.11	2020

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PILLAR 5 – CROSS – CUTTING TOPICS

Objectives: The cross-cutting activity area is structured around three research areas with the following overarching objectives:

Sustainability, LCSA, recycling and eco-design objectives:

1. Develop life cycle thinking tools addressing the three dimensions of sustainable development: economic, social, and environmental.
2. Develop eco-design guidelines and eco-efficient processes.
3. Develop enhanced recovery processes (recycling) in particular for materials belonging to the platinum group, other critical raw materials and per- and polyfluoroalkyl substances.

Education and public awareness objectives:

1. Develop educational and training material and building training programmes for professionals and students on hydrogen and fuel cells.
2. Raise public awareness and trust towards hydrogen technologies and their system benefits.

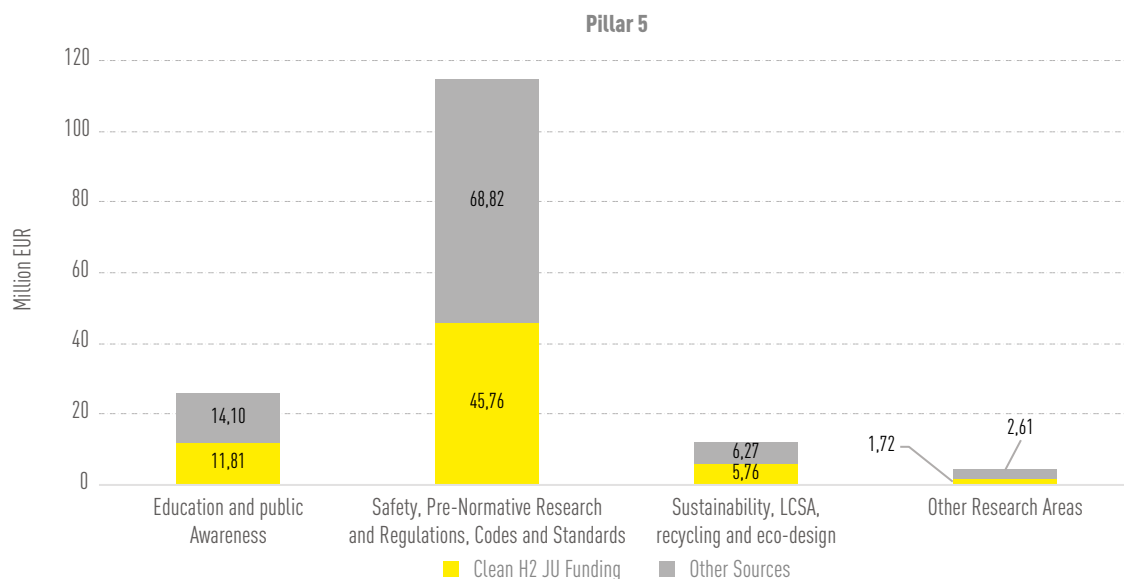
Safety, PNR and RCS objectives:

1. Increase the level of safety of hydrogen technologies and applications.
2. Support the development of RCS for hydrogen technologies and applications, with the focus on standards.

The first research area is critical to ensure that the technology solutions developed by the programme are aligned to the overall principles and goals of the European energy transition towards a decarbonised energy system. The other two fields are enablers for the market penetration of the hydrogen technologies and systems. The development of know-how and skills has to provide the availability of personnel able to design, install and operate hydrogen systems and to face the enormous increase in demand expected in the short term. Similarly, a fit-for-purpose RCS framework will facilitate deployment. It is an enabler for innovation and safety, specifically public safety, which has to be guaranteed along the whole supply chain. The third development line is critical to be able to rank the sustainability of existing and future technology solutions, for instance in terms of their contributions to GHG emission avoidance and decarbonisation targets.

Budget: To date (Project calls from 2008 until 2020), the Partnership's total own contribution was of EUR 65 million complemented by EUR 26 million of other contributions. The distribution of total historical budgets over the three main research areas is shown in Figure 51 and indicates that approximately 85% of funding for Pillar 5 went to support pre-normative research and regulation, codes and standards development and safety. Education and training activities received around 11%. The sustainability dimension shows the lowest value, because relatively new, but will grow considerably in the next years. Moreover, the sustainability dimension will play a more relevant role in the majority of the projects of the Clean Hydrogen JU. The first three bars in Figure 51 correspond to the three research areas considered in the 2022 Programme Assessment, the fourth bar on the far right represents a total of projects belonging to other research areas, now phased-out.

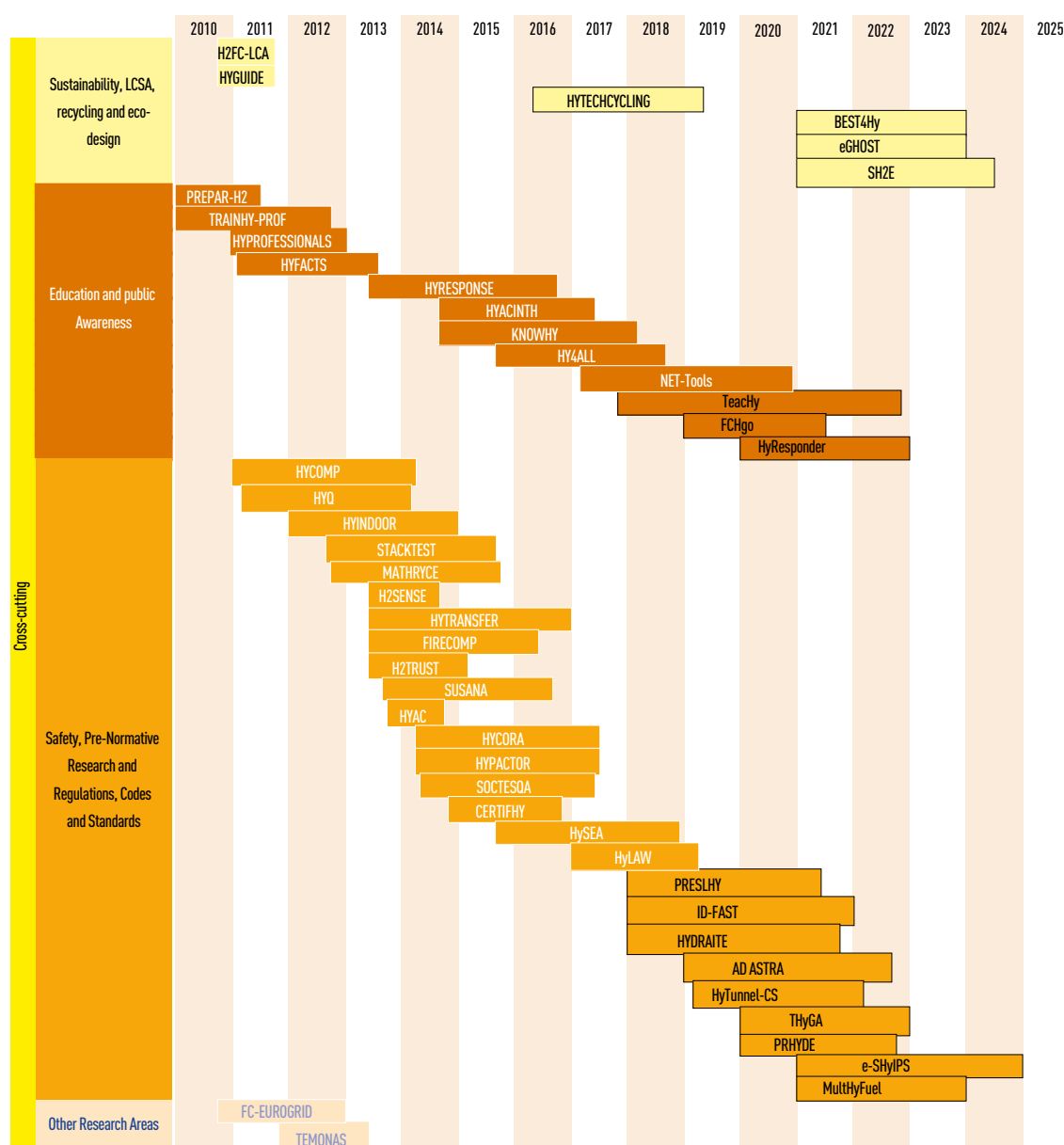
Figure 51: Funding for Pillar 5 projects from 2008 to present.



Source: Clean Hydrogen JU

Projects: The 2022 Programme Assessment covers the 15 projects under Pillar 5, the ones highlighted in black in Figure 52. Since 2010, most projects remain with the Safety, PNR and RCS area, with 10 projects reviewed out of 16 in total, although most of them are expected to be concluded by the end of in 2022.

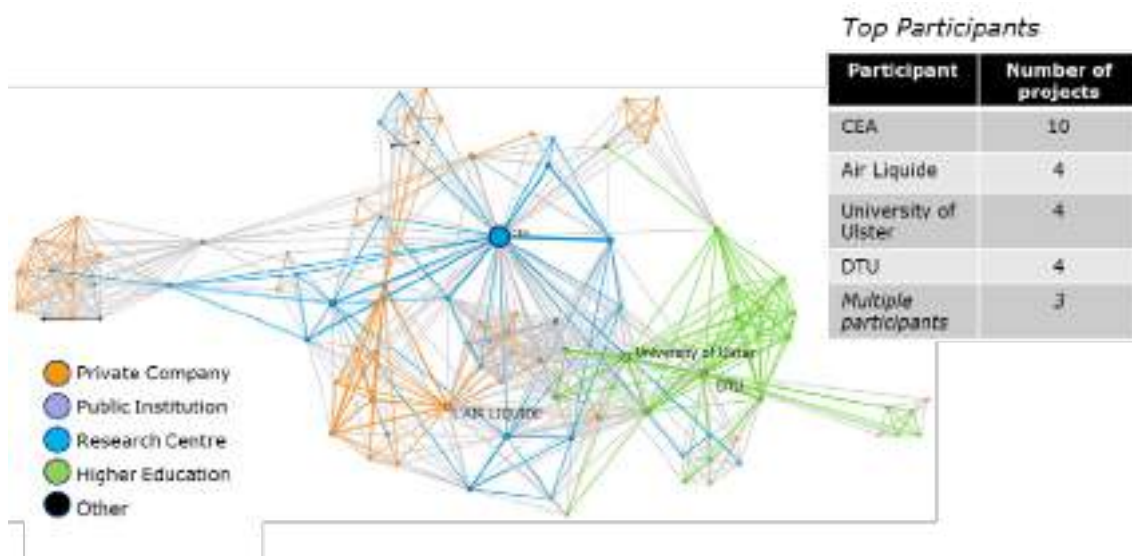
Figure 52: Project timelines of Pillar 5 – Cross – cutting topics. Projects highlighted in black were considered for the 2022 Programme Technical Assessment.



Source: Clean Hydrogen JU

Figure 53 is a plot produced using TIM. This plot shows the connections between partners present in the projects in the Cross-Cutting Pillar. In general, it can be noticed that the public research and academic centres represent the majority in the cross-cutting activities. This is a specific 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 hydrogen behaviour knowledge.

Figure 53: TIM Plot showing the participants in the 15 projects assessed in Cross-Cutting Pillar.¹³⁸



Source: TIM (JRC)

SUSTAINABILITY, LCSA, ECO-DESIGN AND RECYCLING

The project **SH2E** is working on Guidelines for Life Cycle Sustainability Assessment and Prospective Benchmarking. The environmental LCA guidelines build on the FC-HyGUIDE by updating the methodology, filling gaps (e.g., the influence of time and product development in the results), and expanding its applicability (i.e., the intent is to have a methodology that can be applied not only in Europe, but worldwide). In addition, guidelines for life cycle costing (LCC) and social LCAs (S-LCA) will be produced. The final step of the project is the development of a software tool to perform life cycle studies for hydrogen technologies. The results of SH2E will set the basis for a programme-wide adoption of the LCSA methodology, with commitment of every project to align methods, processes, or products to the LCSA principles.

The project **BEST4HY** continues the activities of project HYTECHCYCLING and is developing recycling technologies for material recovery from two FCH products: PEMFC and SOFC. The recycling processes will be brought to TRL 5, and the recycled materials will be validated in terms of quality and performance when re-used in new components and in new stacks. Two novel technologies for PEM recycling (Pt ad ionomer recovery) will be brought to TRL 5, and one novel technology for SOFC recycling (La and Co recovery) will be demonstrated at TRL 3. The project is well aligned to the SRIA target for this research field.

The project **EGHOST** will deliver eco-design guidelines for PEMFC and SOEC, and a white book for the eco-design of any FCH product. The goal is to facilitate future standardisation as well as the categorization of FCH products as eco-efficient and sustainable solutions. So far, the project 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.

¹³⁸. 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.

EDUCATION AND PUBLIC AWARENESS

The project **TEACHY** has developed learning tools and materials addressing in first instance university students (undergraduates and post-graduates) but it includes also vocational training. The overarching goal of the project is to offer students across Europe access to high quality and harmonised training material. TEACHY consortium consists of twelve European Universities working together for the establishment of a European MSc course on fuel cells and hydrogen technologies. The MSc course modules have been used for continuous professional development courses with the participation of engineers and teachers. It is expected that by the end of project, 200 participants will have followed the CPD. The planned massive open online course will be provided at the end of the project.

The project **FCHGO** focused on school pupils in the primary and secondary schools. Project's outcomes range from a toolkit with narrative explanations of the technology, to workshops in classrooms up to a website and an annual award for the best ideas. A guideline for teachers will complete the project products, describing an educational program delivery model. Around 500 pupils have been involved and one award exercise (national and international) was accomplished. To counteract the closure of schools observed during the project due to COVID-19, the project has also developed additional materials to be used by pupils and their families at home during lockdowns.

Project **HYRESPONDER** targets a specific group of professional operators responsible for the training of the first and second responders. It builds on the previous project HYRESPONSE (2013-2016), which targeted first responders. The project has also extracted lessons from other previous projects which have studied general aspects of safety, such as HYINDOOR and NET-TOOLS, and spill over has taken place with ongoing projects PRESLHY and HYTUNNEL-CS. HYRESPONDER completes the already available set of tools of HYRESPONSE by providing a "train the trainer" programme in hydrogen safety throughout Europe. Its fundamentally innovative principle is to involve responders in the permitting process, ensuring the correct incidents management and recovery. The programme consists of a virtual reality tool and educational training tool for trainers of responders. The European Emergency Response Guide developed by project HYRESPONSE is also being revised and expanded to strategies and tactics for incidents involving liquefied hydrogen.

SAFETY, PNR AND RCS

The project **HYDRAITE** has studied the effects of hydrogen contaminants on fuel cell systems in automotive applications. This is a critical aspect related to mobility because impurities originating from the hydrogen supply chain play an important role in the degradation behaviour of the fuel cell system. The project builds upon the results of the previous project HyCORA. A major achievement of the HYDRAITE project is the development in Europe of three certified laboratories capable of measuring hydrogen quality according to European harmonised standard EN 17124:2018 and international standard ISO 14687:2019, which provide equivalent hydrogen fuel product specification and quality assurance requirements.

The project **ID-FAST** has developed Accelerated Stress Tests (AST) for PEMFC for automotive applications and a methodology able to predict ageing. A major part of the work was dedicated to understanding real life degradation behaviour and the identification of the impact of individual stressors. For doing this, the project has used and characterised single cells already aged under realistic automotive conditions by previous projects. The AST tests will allow a shorter testing time by adopting stress tensors aiming at accelerating degradation of FC components simulating worst-case real operations. The present durability tests require so much time, that several projects end before reaching the total number of testing hours required for the evaluation of the lifetime of their prototypes. Therefore, all the FCH 2 JU projects and industries will profit from a shorter testing time when assessing PEMFC durability. The AST is applicable not only to light-duty, but also to heavy-duty vehicles. ID-FAST has also initiated the development of related new standard by IEC/TC 105.

Similarly, the project **AD ASTRA** has developed AST protocols for solid oxide cell stacks, operating in both fuel cell and electrolysis modes for stationary applications. To understand the nature of degradation, the project harvested results from previous FCH 2 JU projects that operated in the field and tested systems that have already

operated for thousands of hours, characterising also microstructural evolutions. The final product is expected to be a set of validated models able to predict degradation of SOEC, correlating the accelerated tests to the real-life operation conditions. An important innovative approach of this project is the recognition of the stochastic dimension of degradation, and its incorporation of the degradation models. This project has already achieved a publication record of 20 peer-reviewed articles.

The project **THYGA's** original scope was testing how domestic and commercial gas appliances (boilers, burners and cookers) perform in the presence of hydrogen up to 60% in volume of the natural gas. As agreed later amongst stakeholders, from a grid's perspective, hydrogen concentration values above 30% seem unlikely technically and economically. Therefore, the project is now refocused on appliances behaviour in presence of hydrogen concentrations up to 30%. For higher values, the plan is to assess the needs for a new certification, the related additional costs and the changes required to the most common types of gas burners. Currently, the project is executing an experimental campaign to identify the concentration limit below which hydrogen can be added to the natural gas without changing existing certification of the appliances.

The project **PRHYDE** studies the parameters and components required for hydrogen refuelling of heavy-duty vehicles, such as trucks and buses, to identify the optimal solutions minimising filling time, maximising travel autonomy and at the same time guaranteeing safety. PRHYDE will recommend a non-proprietary filling protocol, ready for integration in the standard ISO 19885-3 already under preparation by the ISO/TC 197 WG24. Project's scope cover protocols for on-board storage systems with multiple tanks with 35, 50, and 70 MPa nominal working pressures. PRHYDE addresses not only hydrogen refuelling for road transport, but also the rail and water sectors. The outcome of PRHYDE will also contribute to the implementation of the new Regulation on Deployment of Alternative Fuel Infrastructure¹³⁹ (AFIR), via the related standardisation request to the CEN and CENELEC. It seems however that the project did not yet realise this potential and does seem to focus on this new opportunity.

The project **MultHyFuel** will deliver guidelines for the design, construction, and operation of refuelling stations able to deliver at the same location several fuels, including hydrogen. The project has already performed an analysis of the legal framework regarding permitting requirements throughout Europe. Critical accidental scenarios, specific for a multi-fuel refuelling station, have been as well identified. COVID-19 has caused some delays in experimental testing of hydrogen leakage and their consequences, due to unavailability of equipment. MultHyFuel is contributing to the existing database of HyLaw project in the field of current legislation on permitting processes across the EU for the deployment of HRS.

The project **PRESLHY** has studied the safety of LH₂ release under accidental conditions. Despite the mature competences in handling of LH₂ available in specialised companies, new applications characterised by large quantities of hydrogen in non-industrial, near public and confined environments requires a different approach and new fundamental studies on the behaviour of liquid and cryogenic hydrogen releases. The project has provided the scientific community with new information on release, ignition and combustion under realistic conditions. These data have been used to improve and validate the physical models and the simulations used for describing releases.

The project **HYTUNNEL-CS**, which ends this year, has studied the conditions under which public infrastructure can be safely used by hydrogen vehicles. This is an aspect which has not been considered relevant so far, due to the low numbers of hydrogen vehicles and consequently the negligible probability of a hydrogen releases in a tunnel or a public garage. An increase of hydrogen systems and hydrogen quantities on the road and in public spaces is expected, enabled by the objectives of the European hydrogen strategy and the proposed Regulation on the deployment of alternative fuels infrastructure aiming to replace the similar Directive 2014/94/EU. It is important to deliver the data and the methodology required by local and national authorities to grant permission to the use tunnels and underground garages, and to inform all stakeholders of the rules governing safety of the new mobility technology. The project is building on projects HYND00R (2012-15) and HYSEA (2015-18) which have provided data on hydrogen behaviour in semi-confined space.

139. Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the deployment of alternative fuels infrastructure, COM/2021/559 final

E-SHYIP will define a pre-standardisation plan for hydrogen as a fuel for passenger ships. It will contribute to the ongoing work at IMO¹⁴⁰, in updating the IGF Code¹⁴¹ to hydrogen as a fuel. The approach is vessel independent and focuses on the risk and safety assessment methodologies. The experimental and modelling activities are centred around the general arrangement on board, the safe installation of the systems and the effect of marine environment on degradation. The bunkering side will be simulated to understand the refuelling process. The project has 14 formal months of life and tangible results are not yet available.

140. International Maritime Organisation

141. **IMO IGF** (2017): International Code of Safety for Ship Using Gases or Other Low-flashpoint Fuels. It is mainly written for natural gas.

AD ASTRA

HARNESSING DEGRADATION MECHANISMS TO PRESCRIBE ACCELERATED STRESS TESTS FOR THE REALIZATION OF SOC LIFETIME PREDICTION ALGORITHMS



Project ID	825027
PRD 2022 Panel	5 – Cross-cutting
Call topic	FCH-04-3-2018: Accelerated stress testing (AST) protocols for solid oxide fuel cells (SOFC)
Project total costs	EUR 3 008 426
Clean H ₂ max. contribution	EUR 3 008 426
Project period	1/1/2019 – 31/8/2022
Coordinator	Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile, Italy
Beneficiaries	Sunfire GmbH, SOLIDpower SpA, Europäisches Institut für Energieforschung EDF – KIT EWIV, Institute of Electrochemistry and Energy Systems, Università degli Studi di Salerno, École Polytechnique Fédérale de Lausanne, Università degli Studi di Genova, Danmarks Tekniske Universitet, Commissariat à l'énergie atomique et aux énergies alternatives

<https://www.ad-astra.eu>

PROJECT AND OBJECTIVES

Accelerated stress tests deliberately stress a test material, component or product for a short period to assess the stability of new materials without having to use them in an operational system over a long period. The EU-funded AD ASTRA project aims to define accelerated stress testing protocols deduced from a systematic understanding of degradation mechanisms in aged components of solid oxide cell stacks operating in both fuel cell and electrolysis modes. Benchmarking and the first two campaigns of possible accelerated tests have been completed. Their validation is the next step.

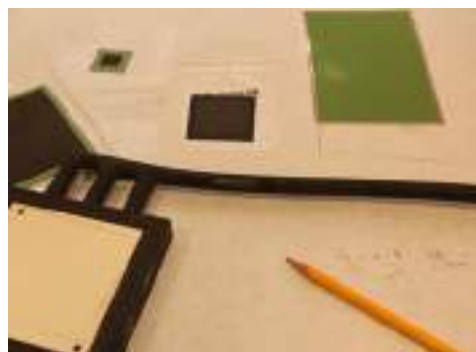
PROGRESS AND MAIN ACHIEVEMENTS

- Over 200 samples from field and laboratory tests have been delivered and analysed.

- An online database was developed for the storing of all data (sample identity details, test conditions, measurement results) in an indexed archive.
- AD ASTRA completed the model for transfer functions developed from accelerated stress test conditions for real-life operation.

FUTURE STEPS AND PLANS

- AD ASTRA will conclude the validation tests and will adopt the schematic description of validated accelerated test procedures. Tests are ongoing, in collaboration with the Joint Research Centre.
- The models are validated and the transfer functions have been incorporated. Different modelling approaches will be considered.



QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Target	Achieved to date by the project	Target achieved?
Project's own objectives	Degradation acceleration	10x	4x	⚙️
	Published articles	2 for each of work packages (WPs) 2, 3 and 4	11 for WP3, 3 for WP4, 5 for WP5	✓
AWP 2018	Submission of NWIP to IEC for standardisation	1	Technical report provided	⚙️

BEST4Hy

SUSTAINABLE SOLUTIONS FOR RECYCLING OF END OF LIFE HYDROGEN TECHNOLOGIES



SUSTAINABLE SOLUTIONS
FOR RECYCLING OF
END-OF-LIFE HYDROGEN
TECHNOLOGIES



Project ID	101007216
PRD 2022 Panel	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
Clean H ₂ max. contribution	EUR 1 586 015
Project period	1/1/2021 – 31/12/2023
Coordinator	Parco Scientifico Tecnologico per l'Ambiente – Environment Park Torino SpA, Italy
Beneficiaries	IDO-Lab GmbH, Hensel Recycling GmbH, ElringKlinger AG, Aktsiaselts Elcogen, Univerza v Ljubljani, RINA Consulting SpA, Politecnico di Torino, Commissariat à l'énergie atomique et aux énergies alternatives
https://best4hy-project.eu/	

PROJECT AND OBJECTIVES

The overall objective of BEST4Hy is 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 products – proton-exchange membrane fuel cells (PEMFCs) and solid oxide fuel cells (SOFC) – and proof of concept for the recovery of iridium and palladium from proton-exchange membrane water electrolysis with novel technologies. Currently, the project is performing validation of four recovery processes at laboratory scale (TRL3) on materials of different ages (PEMFC and SOFC). BEST4Hy is performing life cycle analysis / life cycle cost analysis on fuel cell and hydrogen products and end-of-life processes. The regulatory aspects study / policymakers' involvement and the standardisation aspects started in December 2021.

involvement and the standardisation aspects started in December 2021.

PROGRESS AND MAIN ACHIEVEMENTS

- BEST4Hy achieved Pt recovery via the hydrometallurgical process.
- The project created a novel MEA gaseous-phase dismantling process.
- It achieved Ni-YSZ anode components recovery by HTH and HTM.

FUTURE STEPS AND PLANS

- The TRL 3 processes optimisation is ongoing.
- The project began scaling up the processes to TRL 5 in June 2022, and regulatory and standardisation aspects are ongoing.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Incoming Pt recovered	%	80	
	Incoming anode material recovered in total for SOFC	%	80	
	Incoming Pt recovered	%	90	
	La and Co recovered	%	> 80	
	Incoming membrane	%	100	
	GHG emission reduction in the overall production	%	– 20	

eGHOST

ESTABLISHING ECO-DESIGN GUIDELINES FOR HYDROGEN SYSTEMS AND TECHNOLOGIES



Project ID	101007166
PRD 2022 Panel	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 max. contribution	EUR 998 991.25
Project period	1/1/2021 – 31/12/2023
Coordinator	Fundación IMDEA Energía, Spain
Beneficiaries	Institute of Applied Energy, Symbio, Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón, Univerza v Ljubljani, Commissariat à l'énergie atomique et aux énergies alternatives

<https://eghost.eu/>

PROJECT AND OBJECTIVES

eGHOST will provide the first milestone in the development of ecodesign criteria in the European hydrogen sector. Two guidelines for specific fuel cells 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 TRLs (solid oxide electrolyzers) 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.

FUTURE STEPS AND PLANS

- Product concepts will be completed in month 24. They will be assessed and prioritised as a function of the reduction goals (month 30).
- Methodological and technical ecodesign guidelines for the PEMFC stack will be issued (month 33).
- Methodological and technical ecodesign guidelines for the solid oxide electrolysis cells will be issued (month 33).
- The eGHOST white book will contain the main recommendations for FCH products' eco(re)designing, drawing on the lessons learnt (month 36).

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Achieved to date by the project	Target achieved?
AWP 2020	Ecodesign guidelines	number published	2	
	Cumulative cost reduction	%	3	
	Cumulative environmental reduction	%	10	
	Ecoefficiency improvement	%	10	

E-SHyIPS

ECOSYSTEMIC KNOWLEDGE IN STANDARDS FOR HYDROGEN IMPLEMENTATION ON PASSENGER SHIP



Project ID	101007226
PRD 2022 Panel	5 – Cross-cutting
Call topic	FCH-04-2-2020: PNR on hydrogen-based fuels solutions for passenger ships
Project total costs	EUR 2 500 000
Clean H ₂ max. contribution	EUR 2 500 000
Project period	1/1/2021 – 31/12/2024
Coordinator	Politecnico di Milano, Italy
Beneficiaries	IDF – Ingegneria Del Fuoco SRL, Levante Ferries Naftiki Etairaia, Dimos Andravidas-Kyllinis, Atena scarl – Distretto Alta Tecnologia Energia Ambiente, Teknologian tutkimuskeskus VTT Oy, Ghenova Ingeniería SL, UNI – Ente Italiano di Normazione, DNV Hellas Single Member SA, Oy Woikoski AB, Scheepswerf Damen Gorinchem BV, Danaos Shipping Company Limited, Proton Motor Fuel Cell GmbH, Cineca Consorzio Interuniversitario, Università degli Studi di Napoli Parthenope, Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile

<https://e-shyips.com/>

PROJECT AND OBJECTIVES

Hydrogen is considered an option for reaching emission reduction targets; however, a regulatory framework applicable to hydrogen-fuelled ships is not yet available. e-SHyIPS brings together hydrogen and maritime stakeholders to gather new knowledge based on regulatory framework review and experimental data. The approach is vessel independent, and is focused on the risk and safety assessment methodologies. e-SHyIPS will define a pre-standardisation plan for an International Code of Safety for Ships using Gases or other Low-flashpoint Fuels update for the hydrogen-based-fuels passenger ships and a roadmap to boost the hydrogen maritime economy.

NON-QUANTITATIVE OBJECTIVES

- e-SHyIPS aims to define project concept functional scenarios. In close cooperation with the project's industrial maritime partners, the technical and functional requirements of hydrogen-based-fuels passenger ships will be elicited in operational profile scenarios. Use cases for vessel design will be defined in line with the requirements of industrial maritime partners and the stakeholders.
- The project aims to determine vessel scenario and bunkering functional and technical requirements. The functional and technical requirements are for a scenario report. The technical and functional requirements of hydrogen-based-fuels passenger ships were elicited from operational profile scenarios. The technical features will be described for the associated subsystem (e.g. pumps, hoses, etc.). The metrics and safety-related analyses to be conducted will be communicated and specified for the purposes of the risk assessment process. Operational features, such as bunkering procedures and hydrogen fuel conditions, will also be described, defining the limits for the scope of the analysis.
- The results of the analysis of emergency hydrogen discharge or major leaks from

the vessel are expected at the end of 2022. The test is focused on piping/venting mast arrangements for emergency hydrogen discharge, and the dispersion of hydrogen outside the ship.

- The guidelines for ship design and operation regarding emergency hydrogen discharge for different types and sizes of vessels and hydrogen storages are expected at the end of 2022.
- The project aims to determine risk and safety best practices for the maritime sector. The project will report on technical knowledge gaps and models for risk assessment and risk management of gaseous hydrogen and liquid hydrogen, and hydrogen-based alternative fuels on ships, in 2024.

PROGRESS AND MAIN ACHIEVEMENTS

The project has developed ecosystemic knowledge of standards for hydrogen implementation for passenger ships.

FUTURE STEPS AND PLANS

- e-SHyIPS will continue to develop the hydrodynamic analysis. Implementation on the LincoSim platform is planned for the end of 2022.
- The preliminary vessel design for each scenario is expected to be completed at the end of 2022.
- The H₂-based fuel propulsion system's basic design technical report is expected to be completed by the end of 2022.
- The on-board H₂ dispersion and explosion model test plan, set-up and initial results are expected to be ready for the end of 2022.
- Interim test results from material and component testing and postmortem analysis are expected at the end of 2022.
- Initial results for the fuel delivery and bunkering solutions for ships are expected at the end of 2022.

FCHgo

FUEL CELLS HYDROGEN EDUCATIONAL MODEL FOR SCHOOLS



Project ID	826246
PRD 2022 Panel	5 – Cross-cutting
Call topic	FCH-04-4-2018: Strengthening public acceptance and awareness of FCH technologies by educating pupils at schools
Project total costs	EUR 502 498.75
Clean H ₂ max. contribution	EUR 502 498.75
Project period	1/1/2019 – 30/6/2021
Coordinator	Università degli Studi di Modena e Reggio Emilia, Italy
Beneficiaries	Steinbeis 2i GmbH, InEuropa SRL, Zürcher Hochschule für Angewandte Wissenschaften, Uniwersytet Mikołaja Kopernika w Toruniu, Libera Università di Bolzano, Danmarks Tekniske Universitet

<https://fchgo.eu>

PROJECT AND OBJECTIVES

FCHgo aims to explain the functioning and application of fuel cells and hydrogen (FCH) technologies, and to make younger generations aware of these by providing an educational toolkit that takes a narrative approach, with a website as a connecting point for all users. The final version of the FCHgo toolkit (lessons and materials) for pupils aged 8–18 is freely available, having been tested in classrooms and validated. FCHgo ended on 30 June 2021, after the launch of the first edition of the award for the best idea/solution to employ FCH. Despite problems related to the COVID-19 pandemic, both national and international events were successful.

NON-QUANTITATIVE OBJECTIVES

- FCHgo aimed to develop an educational programme delivery model (EPDM). The final version of the EPDM is made up of an educational toolkit, comprising a set of guidelines,

lessons, toys, plays and videos to support educational activities in European schools. The EPDM is available in 10 languages.

- The project aimed to launch the FCHgo award, providing the possibility for all European students to propose their best idea for future FCH applications. The first award ceremony was successfully carried out.

PROGRESS AND MAIN ACHIEVEMENTS

- The final version of the FCHgo EPDM is available.
- FCHgo award activities were performed.
- The project hosted the first FCHgo award ceremony.

FUTURE STEPS AND PLANS

The project has finished. Partners are planning to organise a second award, depending on whether the necessary financial support can be found.



QUANTITATIVE TARGETS AND STATUS

Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Number of participants in the FCHgo EPDM validation	participants	N/A	32	⚙️
Trained pupils in primary and secondary schools for FCHgo award participation	pupils	200–140 000	457	✓
Trained professionals (teachers) for FCHgo award participation	teachers	N/A	130	⚙️

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HYDRAITE

HYDROGEN DELIVERY RISK ASSESSMENT AND IMPURITY TOLERANCE EVALUATION



Project ID	779475
PRD 2022 Panel	5 – Cross-cutting
Call topic	FCH-04-1-2017: Limiting the impact of contaminants originating from the hydrogen supply chain
Project total costs	EUR 3 499 867.50
Clean H ₂ max. contribution	EUR 3 499 867.50
Project period	1/1/2018 – 30/9/2021
Coordinator	Teknologian tutkimuskeskus VTT Oy, Finland
Beneficiaries	Sintef AS, Zentrum für Brennstoffzellen-Technik GmbH, PowerCell Sweden AB, Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg, NPL Management Limited, Stiftelsen Sintef, Commissariat à l'énergie atomique et aux énergies alternatives

<https://hydraite.eu/>

PROJECT AND OBJECTIVES

The HYDRAITE project aims to solve the issue of hydrogen quality for transportation applications. The effects of contaminants, originating from the hydrogen supply chain, on the fuel cell systems in automotive applications were studied. A hydrogen-refuelling station (HRS) sampling campaign was conducted. In-line monitoring of hydrogen quality at the HRS and a sampling strategy and methodology for new impurities, gases, particles and liquids were evolved. Three European H₂ laboratories were established, capable of measuring all of the contaminants in accordance with International Organization for Standardization (ISO) standard 14687.

NON-QUANTITATIVE OBJECTIVES

- HYDRAITE aims to make recommendations for the revision of ISO standard 14687. Similar measurement set-ups of six partners were undertaken, the methodology was validated and fuel cell measurements were completed with CO, CO₂, sulphur, ionic liquids, freon and toluene.
- The project aims to make recommendations for fuel cell stack contaminant measurements in automotive-type operations. These recommendations have been created.

- It aims to gather technical data on fuel composition from HRSs. Three sampling campaigns have been conducted, with a total of 30 samples collected.
- HYDRAITE aims to perform in-line monitoring of hydrogen fuel quality. The concept for the proton-exchange-membrane-based sensor and HRS online quality monitoring were established.
- The project aims for three European laboratories to measure the ISO-defined contaminants. Three project laboratories are using analytical methods compliant with ISO standard 14687.

PROGRESS AND MAIN ACHIEVEMENTS

- The project set up three European hydrogen-quality laboratories capable of full analysis in accordance with European Standard EN 17124.
- Three HRS sampling campaigns were completed, collecting public data from a total of 30 samples from Germany, Norway and Sweden.
- HYDRAITE validated the methodology for studying the effect of impurities on fuel cell stacks.

FUTURE STEPS AND PLANS

The project has finished.



HyResponder

EUROPEAN HYDROGEN TRAIN THE TRAINER PROGRAMME FOR RESPONDERS

Project ID	875089
PRD 2022 Panel	5 – Cross-cutting
Call topic	FCH-04-1-2019: Training of Responders
Project total costs	EUR 1 000 000
Clean H ₂ max. contribution	EUR 1 000 000
Project period	1/1/2020 – 31/12/2022
Coordinator	University of Ulster, United Kingdom
Beneficiaries	Fire Service College Limited, International Fire Academy, Ministry of the Interior of the Czech Republic, Universitetet i Sørøst-Norge, Landes-Feuerwehrverband Tirol, Persee, Crisis Simulation Engineering SARL, École nationale supérieure des officiers de sapeurs-pompiers, Service Public Fédéral Intérieur, Ayuntamiento de Zaragoza, Association Comité National Français du CTIF (Comité Technique International de prévention et d'extinction de Feu), DLR-Institut für Vernetzte Energiesysteme EV, L'Air Liquide SA, Deutsches Zentrum für Luft- und Raumfahrt EV, Università degli Studi di Roma la Sapienza, Commissariat à l'énergie atomique et aux énergies alternatives

<https://hyresponder.eu/>

PROJECT AND OBJECTIVES

The aim of HyResponder is to develop and implement a sustainable trainers' programme on hydrogen safety for responders throughout Europe. 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 will be 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 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.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Target	Achieved to date by the project	Target achieved?
Project's own objectives	Training events (1 train the trainer; 10 national)	11	2	⚙️
	Threefold training materials (lectures, operational, virtual reality)	3	3	✓
	Revised <i>European Emergency Response Guide</i>	1	1	✓
	e-platform for responders	1	1	✓
	Materials translated into eight languages	8	1	⚙️

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 were developed to support the remote training of responders.

FUTURE STEPS AND PLANS

- HyResponder will deliver regional workshops. Countries' schedules have been revised, with the exception of that of Austria, to allow for in-person training in ENSOSP in June 2022. Online training has been piloted in Austria. As of June 2022, nine regional workshops are still to be held. These will be completed by April 2023.
- The project will complete translation of training materials. This is partially complete; it is expected to be completed by the end of April 2022.
- HyResponder will demonstrate the project's impact nationally. Each partner has a plan to ensure that the HyResponder training has an impact within and beyond HyResponder. The project consortium will document this.

HyTunnel-CS

PNR FOR SAFETY OF HYDROGEN DRIVEN VEHICLES
AND TRANSPORT THROUGH TUNNELS AND SIMILAR
CONFINED SPACES



Project ID	826193
PRD 2022 Panel	5 – Cross-cutting
Call topic	FCH-04-1-2018: PNR for safety of hydrogen driven vehicles and transport through tunnels and similar confined spaces
Project total costs	EUR 2 500 000
Clean H ₂ max. contribution	EUR 2 500 000
Project period	1/3/2019 – 31/7/2022
Coordinator	University of Ulster, United Kingdom
Beneficiaries	International Fire Academy, Universitetet i Sørøst-Norge, Service Public Fédéral Interieur, Pro-Science – Gesellschaft für wissenschaftliche und technische Dienstleistungen mbH, Karlsruher Institut für Technologie, Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón, Health and Safety Executive (HSE), Stichting Koninklijk Nederlands Normalisatie Instituut, National Centre of Scientific Research 'Demokritos', Università degli Studi di Roma la Sapienza, Danmarks Tekniske Universitet, Commissariat à l'énergie atomique et aux énergies alternatives (CEA)

<https://hytunnel.net>

PROJECT AND OBJECTIVES

This pre-normative research project aims to improve the safety of hydrogen-driven vehicles in underground infrastructure. The project aims to synthesise analytical, numerical and experimental research to produce recommendations for intervention strategies and tactics for first responders, recommendations for the safer use of hydrogen vehicles in underground transportation systems and recommendations for regulations, codes and standards (RCS). HyTunnel-CS aims to reduce over-conservatism in infrastructure safety design for hydrogen accidents and to reduce the costs of underground systems. The outcomes can be directly implemented in relevant RCS.

NON-QUANTITATIVE OBJECTIVES

The project aims to ensure that fuel cell electric vehicles entering tunnels are at a level of risk equal to / below that of fossil fuel vehicles. This is being addressed by considering tunnel vehicles as a system through experimental, theoretical and numerical studies.

PROGRESS AND MAIN ACHIEVEMENTS

- The analytical, numerical, small- to medium-scale experimental research programme is being carried out as planned.
- The large-scale experimental programme in a real tunnel (CEA) was completed. The large-scale experimental programme at the HSE is ongoing.

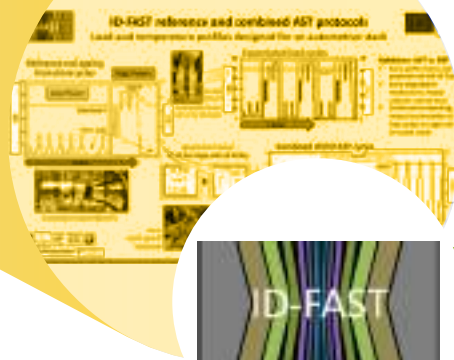
- Two out of three key public deliverables are complete. The remaining key public deliverable is under development.

FUTURE STEPS AND PLANS

- HyTunnel-CS will undertake an analytical and numerical campaign. This will involve the finalisation of the remaining analytical studies, and the validation of computational fluid dynamics simulations against large-scale experimental programme results. The work is in its final stage – the remaining modelling campaign is to be finished after completion of the HSE large-scale experimental programme (June 2022).
- The project will undertake an experimental campaign, fulfilling the experimental programme on hydrogen releases, fires and deflagrations. The large-scale experimental programme has been delayed; it is expected to be completed in June 2022.
- It will undertake a communication campaign. The results will be communicated at the dissemination conference, rescheduled for July 2022.
- HyTunnel-CS will make recommendations for the inherently safer use of hydrogen vehicles, for RCS and for response to hydrogen accidents. The recommendations for RCS have been provided, together with the recommendations for response to hydrogen accidents. The recommendations for the inherently safer use of hydrogen vehicles have been rescheduled.

ID-FAST

INVESTIGATIONS ON DEGRADATION MECHANISMS AND DEFINITION OF PROTOCOLS FOR PEM FUEL CELLS ACCELERATED STRESS TESTING



Project ID	779565
PRD 2022 Panel	5 – Cross-cutting
Call topic	FCH-04-5-2017: definition of accelerated stress testing (AST) protocols deduced from understanding of degradation mechanisms of aged stack components in fuel cell systems
Project total costs	EUR 2 748 195
Clean H ₂ max. contribution	EUR 2 748 195
Project period	1/1/2018 – 31/12/2021
Coordinator	Commissariat à l'énergie atomique et aux énergies alternatives, France
Beneficiaries	Symbio, Freudenberg Performance Materials SE & Co KG, Freudenberg Technology Innovation SE & Co. KG, Bayerische Motoren Werke Aktiengesellschaft, Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg, Politecnico di Milano, Deutsches Zentrum für Luft- und Raumfahrt EV, Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung EV

<https://www.id-fast.eu/index.php?id=1>

PROJECT AND OBJECTIVES

ID-FAST targets the deployment of proton-exchange membrane fuel cells (PEMFC) thanks to specific accelerated stress tests (ASTs) and the link to real durability. The core focus is understanding degradation and the validation of new ASTs relating to in situ, ex situ and modelling data. Postmortem analyses after ageing and modelling are providing insights on the mechanisms involved. Experiments on and simulations of stressors allow ID-FAST to propose accelerating protocols applied in single cells. Combined AST protocols were developed and validated in single cells and stacks with regard to their relevance and their capability to reduce testing time compared with that of real ageing.

NON-QUANTITATIVE OBJECTIVES

- ID-FAST aimed to identify real ageing mechanisms and the impact of conditions. The mechanisms identified include local issues from postmortem analyses of stack components aged in real ageing profiles.
- The project aimed to develop models and couple mechanisms for ASTs' simulation. It aimed to perform new simulations of AST cycles for single cells or stacks, with models including catalyst degradation.
- It aimed to develop and validate specific and combined AST protocols. Two types of operando AST with combined cycles based on low-power/high-power periods of real drive cycles were validated.

- ID-FAST aimed to propose transfer functions relating accelerated degradation to real degradation. The assessment of acceleration factors gave values from 2 to 10, depending on the ASTs. The transfer function was determined as a 1 : 1 ratio for reference cycles and new combined low-power/high-power AST cycles.
- The project aimed to support standardisation efforts of fuel cell testing related to ASTs. A public report with recommendations and contributions to Ad Hoc Group 11 of the International Electrotechnical Commission Technical Committee 105 was started in 2019, dedicated to ASTs for fuel cells, in collaboration with the solid oxide fuel cell project AD ASTRA.

PROGRESS AND MAIN ACHIEVEMENTS

- ID-FAST identified the main stressors and acceleration mechanisms for membrane electrode assembly (MEA) components using specific ageing tests in cells or stacks and postmortem analyses.
- The project simulated AST cycles, including catalyst degradation.
- It defined the operando combined AST with low-power/high-power periods based on ID-FAST drive cycles.

FUTURE STEPS AND PLANS

The project has finished.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Target	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
Project's own objectives	Reduction of the gap in degradation understanding	Improvement	✓	Analyses of MEAs' degradation mechanisms (exp. and model)	2020
	Acceleration factor	2–10	✓	N/A (limited SoA on combined AST representative of the real world)	N/A
	ASTs	New (different combined protocols)	✓	Single-mechanisms AST available for catalyst-coated membrane components	2018

MultHyFuel

MULTI-FUEL HYDROGEN REFUELING STATIONS (HRS): A CO-CREATION STUDY AND EXPERIMENTATION TO OVERCOME TECHNICAL AND ADMINISTRATIVE BARRIERS

Project ID	101006794
PRD 2022 Panel	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 max. contribution	EUR 1 997 406.25
Project period	1/1/2021 – 31/12/2023
Coordinator	Hydrogen Europe, Belgium
Beneficiaries	Shell Nederland Verkoopmaatschappij BV, Snam SpA, Kiwa Nederland BV, ITM Power (Trading) Limited, Health and Safety Executive, Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg, Institut national de l'environnement industriel et des risques, ENGIE, L'Air Liquide SA

<https://multihyfuel.eu/>

PROJECT AND OBJECTIVES

MultHyFuel's ultimate goal is the amendment of best-practice guidelines for the design, construction and development of multi-fuel-refuelling stations. An analysis of the current legal framework regarding permitting requirements throughout Europe was previously 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 safety improvement by selecting the critical scenarios identified in a multi-fuel-refuelling station and proceeding to experimental testing of hydrogen leakage and its consequences.


FUTURE STEPS AND PLANS

- MultHyFuel will complete testing on the leakage characteristics of the dispenser.

The project is waiting for equipment to be delivered and to acquire the data needed for the correct design of the system – testing is expected to start before summer 2022.

- The project will complete testing of leakage consequences (fire and explosion) in the forecourt. It is waiting for equipment to be delivered and for the forecourt replica design to be finalised – testing is expected to start before summer 2022.
- MultHyFuel will organise a workshop with hydrogen-refuelling station operators and public authorities. This is to take place once results from the experimental work package 2 are ready, so they can be presented to the important stakeholders and so that feedback can be acquired.
- The project will perform a risk assessment and an amendment of the best-practice guidelines. These are to take place once the experimental results have been released.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target achieved?	SoA result achieved to date (by others)
Project's own objectives	Safety distance	m		5–35, depending on the country
	Number of authorities represented at the workshops	number		N/A

PRESLHY

PRE-NORMATIVE RESEARCH FOR SAFE USE OF LIQUID HYDROGEN

Project ID	779613
PRD 2022 Panel	5 – Cross-cutting
Call topic	FCH-04-4-2017: PNR for a safe use of liquid hydrogen
Project total costs	EUR 1 905 862.50
Clean H ₂ max. contribution	EUR 1 724 277
Project period	1/1/2018 – 31/5/2021
Coordinator	Karlsruher Institut für Technologie, Germany
Beneficiaries	International Association for Hydrogen Safety, Pro-Science – Gesellschaft für wissenschaftliche und technische Dienstleistungen mbH, Health and Safety Executive, University of Ulster, Institut national de l'environnement industriel et des risques, L'Air Liquide SA, University of Warwick, National Centre of Scientific Research 'Demokritos'

<http://www.preslhy.eu/>

PROJECT AND OBJECTIVES

In the PRESLHY project, the project consortium conducted pre-normative research on the safe use of cryogenic/liquid hydrogen in non-industrial settings. The work programme consisted of a preparatory phase, a main phase for executing a concise experimental programme and a final phase for the exploitation of the experimental outcomes. The results are currently being used to update International Organization for Standardization standard ISO/TR 15916 with regard to cryogenic aspects under subtask 2 of Working Group 29.

NON-QUANTITATIVE OBJECTIVES

PRESLHY aims to make recommendations for a non-proprietary heavy-duty refuelling protocol to be used for future standardisation activities for heavy-duty hydrogen refuelling. Refuelling concepts have been developed and are being validated by experimental and simulation tests for 35, 50 and 70 MPa hydrogen refuelling.



The risk assessment has been performed. The results are to be disseminated to several stakeholders.

PROGRESS AND MAIN ACHIEVEMENTS

- The project has supported the review of ISO/TR 15916 on the safe use of LH₂ in non-industrial settings.
- PRESLHY has produced a handbook chapter on the safety of LH₂.

FUTURE STEPS AND PLANS

- The project will finalise the experimental and simulations work on the fuelling protocol by mid 2022.
- Dissemination workshops were planned for April and May 2022 to present intermediate results. The final dissemination is planned for after the project's end (September 2022).
- PRESLHY will finalise the refuelling protocol concept and carry out final dissemination by September 2022.



QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Target	Achieved to date by the project	Target achieved?
Support for RCS development	Number of reports sent to SDOs	1	4	✓
	Number of workshops with SDOs invited	1	4	
	Consortium partners involved in SDOs	1	5	
	Review of standard initiated	1	1	

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PRHYDE

PROTOCOL FOR HEAVY DUTY HYDROGEN REFUELLING



PROJECT AND OBJECTIVES

The PRHYDE project is aiming to develop recommendations for a non-proprietary heavy-duty refuelling protocol used for future standardisation activities for trucks and other heavy-duty transport systems applying hydrogen technologies. Based on existing fuelling protocols and the current state-of-the-art methods for compressed (gaseous) hydrogen fuelling, different hydrogen fuelling concepts are to be developed

for large tank systems with 35, 50 and 70 MPa nominal working pressures using simulations and experimental verification.

PROGRESS AND MAIN ACHIEVEMENTS

- PRHYDE ran webinars.
- The project has published several deliverables to date.
- It conducted a survey of interested stakeholders outside the project consortium.

Project ID	874997
PRD 2022 Panel	5 – Cross-cutting
Call topic	FCH-04-2-2019: Refuelling protocols for medium and heavy-duty vehicles
Project total costs	EUR 3 167 078.16
Clean H ₂ max. contribution	EUR 1 494 417.00
Project period	1/1/2020 – 31/12/2021
Coordinator	Ludwig-Bölkow-Systemtechnik GmbH, Germany
Beneficiaries	Toyota Motor North America, Nikola Corporation, Shell Deutschland Oil GmbH, ITM Power (Trading) Limited, Zentrum für Brennstoffzellen-Technik GmbH, Nel Hydrogen AS, Toyota Motor Europe NV, ENGIE, L'Air Liquide SA, Commissariat à l'énergie atomique et aux énergies alternatives

<https://prhyde.eu/>



QUANTITATIVE TARGETS AND STATUS

Parameter	Target	Achieved to date by the project	Target achieved?
Meetings with standards organisation groupings	4	3	
Reports sent to standards-developing organisations	18	10	
Publicly accessible workshops/webinars	6	4	

SH2E

SUSTAINABILITY ASSESSMENT OF HARMONISED HYDROGEN ENERGY SYSTEMS: GUIDELINES FOR LIFE CYCLE SUSTAINABILITY ASSESSMENT AND PROSPECTIVE BENCHMARKING

Project ID	101007163
PRD 2022 Panel	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 max. contribution	EUR 1 997 616.25
Project period	1/1/2021 – 30/6/2024
Coordinator	Fundación IMDEA Energía, Spain
Beneficiaries	The Institute of Applied Energy, Symbio, Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón, GreenDelta GmbH, Forschungszentrum Jülich GmbH, Commissariat à l'énergie atomique et aux énergies alternatives

<https://sh2e.eu/>

PROJECT AND 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 cells and hydrogen (FCH) systems. To that end, SH2E will develop and demonstrate specific guidelines for the environmental, economic and social life cycle assessments 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 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's

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.

FUTURE STEPS AND PLANS

- Environmental LCA guidelines will be issued in mid 2022.
- Life cycle cost assessment guidelines will be issued in month 24 (at the end of 2022).
- Social life cycle assessment guidelines will be issued in mid 2023.
- LCSA guidelines will be issued at the end of 2023.
- The software tool for performing FCH LC studies will be issued in month 36.

TeachHy

TEACHING FUEL CELL AND HYDROGEN SCIENCE
AND ENGINEERING ACROSS EUROPE WITHIN
HORIZON 2020



Project ID	779730
PRD 2022 Panel	5 – Cross-cutting
Call topic	FCH-04-3-2017: European Higher Training Network in Fuel Cells and Hydrogen
Project total costs	EUR 1 248 528.75
Clean H ₂ max. contribution	EUR 1 248 528.75
Project period	1/11/2017 – 31/10/2022
Coordinator	University of Birmingham, United Kingdom
Beneficiaries	Karlsruher Institut für Technologie, National Technical University of Ukraine 'Igor Sikorsky Kyiv Polytechnic Institute', Universitatea Politehnica Din București, Vysoká škola chemicko-technologická v Praze (VSCHT), Institut polytechnique de Grenoble, University of Ulster, École Polytechnique Fédérale de Lausanne, Technische Universiteit Delft, Politecnico di Torino, Université Libre de Bruxelles, Danmarks Tekniske Universitet

<http://www.teachy.eu/>

PROJECT AND OBJECTIVES

The project has developed an MSc programme on fuel cells and hydrogen. The MSc modules are also being offered as part of continuous professional development (CPD). Currently, the first run of the MSc programme is coming to a close, with the first student cohort starting their final research projects. Approximately 150 engineers and college teachers have been trained using the CPD modules, with 50 more to be added by the end of the project. The programme is being transferred from the University of Birmingham to VSCHT in Prague, with the programme expected to start there in September 2022.

NON-QUANTITATIVE OBJECTIVES

TeachHy aimed to develop an accreditation system for CPD modules, despite the substantial

challenges in achieving this.

PROGRESS AND MAIN ACHIEVEMENTS

- The MSc programme was created.
- The CPD modules were created.
- The project ensured the transferability of the learning management system (LMS) content.

FUTURE STEPS AND PLANS

- The project aims to transfer the programme to more universities; it is waiting for the results of the transfer to VSCHT.
- TeachHy will develop tools for transfer between different LMSs.
- The project will develop concise CPD programmes.
- It will establish a business entity for post-project activities.



QUANTITATIVE TARGETS AND STATUS

Parameter	Unit	Target	Achieved by the project	Target achieved?
Start of the MSc course	date	October 2019	October 2021	✓
Minimum of 12 modules established on LMS	number of modules	12	15	
Used the MSc modules for CPD delivery	modules run	N/A	8	⚙️
Modules translated into various languages	number of modules	12	6 (partly)	⚙️

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THyGA

TESTING HYDROGEN ADMIXTURE FOR GAS APPLICATIONS

Project ID	874983
PRD 2022 Panel	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 max. contribution	EUR 2 468 826.25
Project period	1/1/2020 – 31/12/2022
Coordinator	ENGIE, France
Beneficiaries	Dansk Gasteknisk Center AS, BDR Thermea Group BV, Gerg-Le Groupe Europeen de Recherches Gazières, Gas.Be, Gaswärme-Institut Essen EV, DVGW Deutscher Verein des Gas- und Wasserfaches EV – Technisch-wissenschaftlicher Verein, Electrolux Italia SpA, Commissariat à l'énergie atomique et aux énergies alternatives

<https://thyga-project.eu/>

PROJECT AND OBJECTIVES

The THyGA project is investigating the amount of hydrogen that can be injected without compromising the safety, emissions and efficiency of existing and new applications. It focuses 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 are to close knowledge gaps on the impact of H₂NG blends, support standardisation activities and identify potential mitigation opportunities.

NON-QUANTITATIVE OBJECTIVES

- THyGA aims 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 aims to have an international reach. THyGA's test protocol has been requested by international partners (in

Canada, Chile and the United States) to be used as a test reference.

PROGRESS AND MAIN ACHIEVEMENTS

- THyGA has completed tests of around 40 appliances.

FUTURE STEPS AND PLANS

- The project will complete the test campaign. To date, around 40 % of the test objectives have been achieved; the goal is to conduct 100 tests by September 2022.
- THyGA will gain the support of the stakeholders regarding standardisation. THyGA has already had many exchanges with technical committees, and plans to develop a common work programme to support the standardisation and certification of H₂NG for appliances.
- The project will develop approaches aiming to identify the technical possibilities of mitigation to improve the rate of H₂ with which appliances can deal (in terms of safety, efficiency, power, etc.).

QUANTITATIVE TARGETS AND STATUS

Target source	Target	Achieved to date by the project
Project's own objectives	Understanding the actual theoretical and experimental information on the impact of H ₂ NG blends on combustion	Five public deliverables
	Understanding the actual theoretical and experimental information on the impact of H ₂ NG blends on materials	Bibliography review and preparation of test rig
	Segmentation of the types of appliances	Segmentation validated with stakeholders (advisory panel group)
	Tests of up to 100 appliances	40 % of tests complete
	Establishing how the existing certification can be modified to allow higher concentrations, including the related additional costs and the required changes to common gas burners	State-of-the-art reports
	Recommendations for revision of EN for ISO standards, or drafting of new standards based on PNR results and a review of the existing testing methods	Ongoing

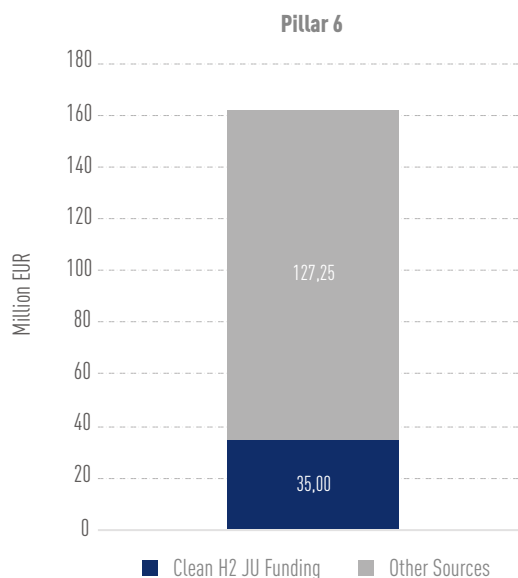
PILLAR 6 – HYDROGEN VALLEYS

Objectives: Hydrogen Valleys can showcase the value proposition of hydrogen in particular for sector integration. The SRIA sees the main focus on system integration and valorisation of hydrogen for use in mobility, as industrial feedstock or to provide power and heat. A key objective of this Pillar is to demonstrate the notion of “system efficiency and resilience”. Market creation is together with support to the development of appropriate regulations and standards is also seen as crucial in order to accelerate the deployment of Hydrogen Valleys across Europe.

There should also be a focus on knowledge management, with an assessment of the socio-economic and environmental impacts. Public awareness of hydrogen technologies can be increased, and the development of Hydrogen Valleys in areas of Europe with no or limited presence of hydrogen technologies should be encouraged. The AWP 2022 call topic in Hydrogen Valleys mentions that projects should build links to hydrogen production or use outside of the Valley itself, which is an interesting expansion of the concept.

Budget: As can be observed from Figure 54, the funding percentage for Hydrogen Valley projects from the JU is just a part of their total funding, at an average of 22%, as they rely mainly on external sources of funding and/or financing. Only the project BIG HIT from the FCH JU call 2015 was funded at 65%.

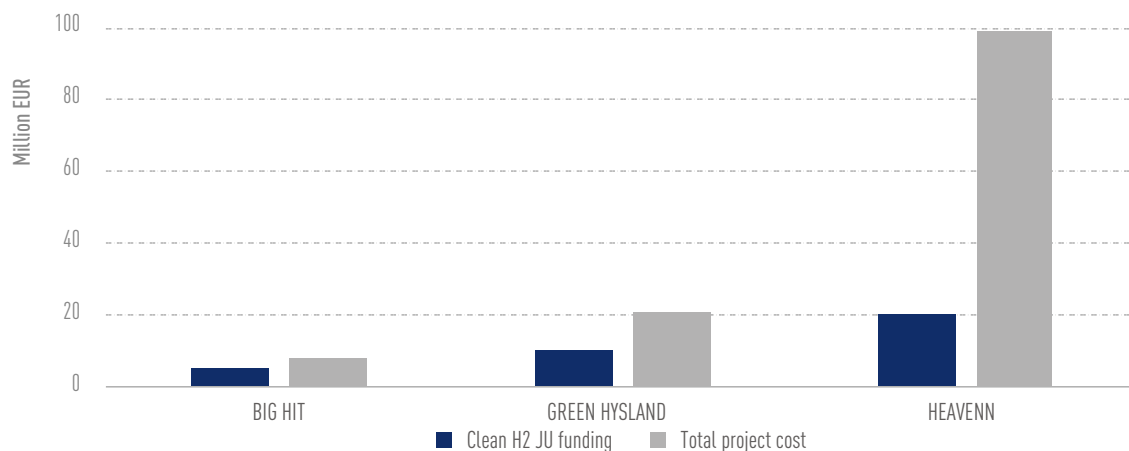
Figure 54: Funding for Pillar 6 projects from 2008 to present.



Source: Clean Hydrogen JU

The 3 projects in this pillar have very different scales in terms of hydrogen production and accordingly on the necessary investments. Figure 55 shows that the total budget of the HEAVENN project is more than 10 times that of BIG HIT.

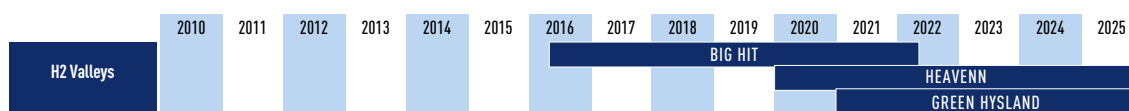
Figure 55: Clean Hydrogen JU funding and total project cost for Pillar 6.



Source: Clean Hydrogen JU

Projects: Three projects are contributing to this Research area, namely BIG HIT, HEAVENN and GREEN HYSLAND, covering the period between 2016 and 2022 (Figure 56). The description of the projects can be found in Section 5.6.

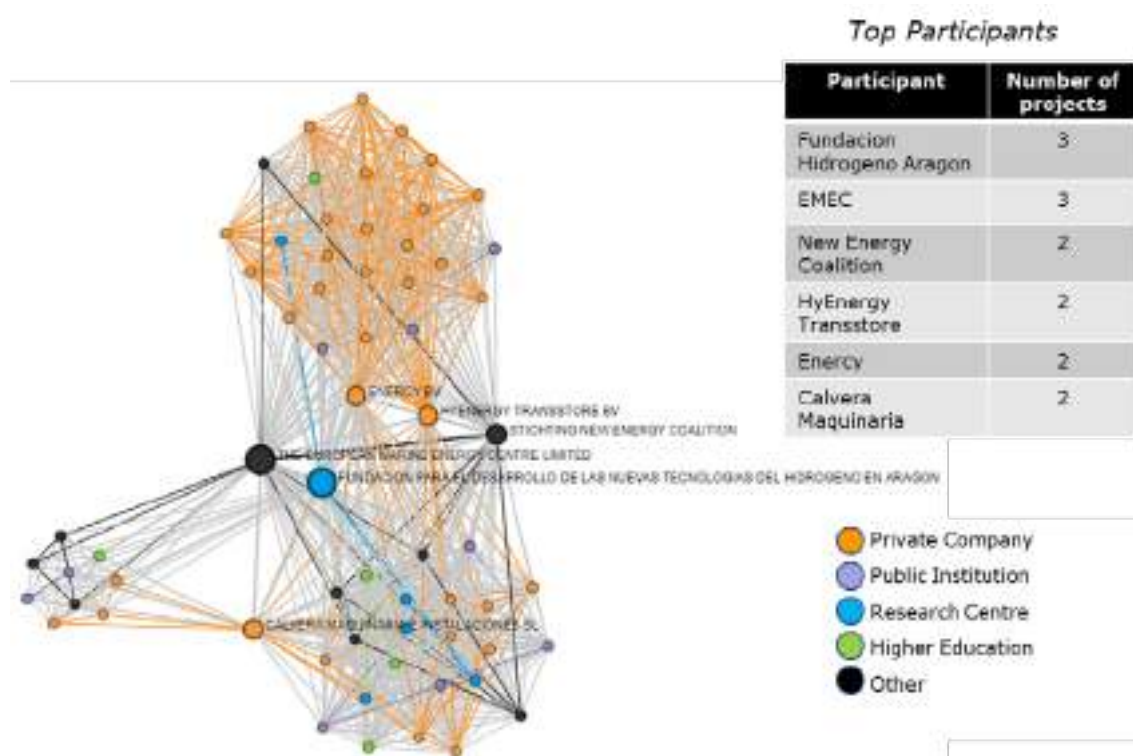
Figure 56: Project timelines of Pillar 6 – Hydrogen valleys. Projects highlighted in black were considered for the 2022 Programme Technical Assessment.



Source: Clean Hydrogen JU

The projects are well connected to each other, as can be seen from Figure 57. The HEAVENN project has a high share of private companies (top cluster).

Figure 57: TIM Plot showing the participants in the 3 projects in Pillar 6.



Source: TIM (JRC)

BIG HIT

BUILDING INNOVATIVE GREEN HYDROGEN SYSTEMS IN AN ISOLATED TERRITORY: A PILOT FOR EUROPE

Project ID	700092
PRD 2022 Panel	6 – H2 valleys
Call topic	FCH-03.2-2015: Hydrogen territories
Project total costs	EUR 7 748 848
Clean H ₂ max. contribution	EUR 5 000 000
Project period	1/5/2016 – 30/4/2022
Coordinator	Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón, Spain
Beneficiaries	Calvera Maquinaria e Instalaciones SL, Scottish Hydrogen And Fuel Cell Association Ltd, Shapinsay Development Trust, Community Energy Scotland Limited, Ministry For Transport, Infrastructure and Capital Projects, Orkney Islands Council, Giacomini SpA, Symbio, ITM Power (Trading) Limited, The European Marine Energy Centre Limited, Danmarks Tekniske Universitet

<http://www.bighit.eu/>

PROJECT AND OBJECTIVES

The BIG HIT project is a major first step towards creating a genuine hydrogen territory in the Orkney Islands. Orkney has over 50 MW of installed wind, wave and tidal capacity, generating over 46 GWh of renewable power per year, and it has been a net exporter of electricity since 2013. Hydrogen is proposed as a solution to minimise the curtailment problems in Orkney caused by the weak connection with the UK mainland. The hydrogen produced is used in thermal, power (cogeneration) and transport applications locally.

NON-QUANTITATIVE OBJECTIVES

- BIG HIT aimed to perform a life cycle assessment study; this is now complete. The first report has been submitted, and the final report will be produced at the end of the project, including operational data.
- The project aimed to perform a business model study for integrated energy systems based on hydrogen technologies across the islands. The first report has been submitted; the final report will be produced at the end of the project, including operational data.
- It aimed to perform a social life cycle assessment. The first report has been submitted; the final report will be produced at the end of the project, including operational data.
- The project aimed to set up the Hydrogen Territories Platform; this platform has been launched. Four webinars have been conducted to date.

The platform will be used in the HEAVENN and Green Hysland projects.

- BIG HIT aimed to perform a first analysis of lessons learnt in the project about the connection of electrolyzers in power grids with high penetration of renewable energy sources (optimal model), marinisation of electrolyzers, etc.

PROGRESS AND MAIN ACHIEVEMENTS

- The main project equipment has been built: 5 H₂ trailers (250 kg of H₂ storage), a H₂ catalytic boiler (30 kW), a 1 MW electrolyser, 5 H₂ fuel cell vans and a 75 kW fuel cell (cogeneration).
- The project developed the logistics of moving hydrogen through an archipelago (a multi-element gas container moving H₂ between the islands by ferry, logistics optimisation).
- BIG HIT developed the Hydrogen Territories Platform.

FUTURE STEPS AND PLANS

- The project will finish in 2022, and a final project event will be hosted in Orkney by June 2022.
- BIG HIT will perform an impact analysis. Final reports on the environmental and social impact and the business model analysis will be published and made available to the public.
- The main project results, conclusions and lessons learnt will be presented at the final project event.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
MAWP Addendum (2018–2020)	Demonstration of a hydrogen catalytic boiler (thermostatic application)				
	Power	kW	40	30	⚙️
	Availability of fuel cell light-duty vehicles (including cars) – fuel cell vans in BIG HIT				
	Availability	%	98	98	✓
	Hydrogen-refuelling stations' durability				
	Time	years	10	Fourth year of operation	⚙️

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GREEN HYSLAND

DEPLOYMENT OF A H₂ ECOSYSTEM ON THE ISLAND OF MALLORCA



GREEN HYSLAND

Project ID	101007201
PRD 2022 Panel	6 – H2 valleys
Call topic	FCH-03-2-2020: Decarbonising islands using renewable energies and hydrogen – H2 islands
Project total costs	EUR 20 453 569.28
Clean H ₂ max. contribution	EUR 9 999 999.50
Project period	1/1/2021 – 31/12/2025
Coordinator	Enagás SA, Spain
Beneficiaries	Redexis Gas Servicios SL, Hycologne GmbH, Ajuntament de Lloseta, Asociación Ibérica de Gasnatural y Renovable para la Movilidad, Asociación Chilena de Hidrógeno, Instituto Balear De La Energía, Gemeente Ameland, Enercy BV, HyEnergy TransStore BV, Stichting New Energy Coalition, Redexis Gas SA, Energy Co-operatives Ireland Limited, Calvera Maquinaria e Instalaciones SL, Asociación Española del Hidrógeno, Autoridad Portuaria de Baleares, Consultoria Técnica Naval Valenciana SL, Diktyo Aeiforikon Nison Toy Aigaiousae, Empresa Municipal de Transportes Urbans de Palma de Mallorca SA (EMT Palma), Centro Nacional De Experimentación de Tecnologías de Hidrógeno y Pilas de Combustible Consorcio, Baleària Eurolíneas Marítimas SA, Acciona Generación Renovable SA., Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón, Fédération européenne des agences et des régions pour l'énergie et l'environnement, European Marine Energy Centre Limited, Agência Regional da Energia e Ambiente da Região Autónoma da Madeira, Universidad de La Laguna, Universitat de les Illes Balears, National University of Ireland Galway, Commissariat à l'énergie atomique et aux énergies alternatives

<https://greenhysland.eu/>

PROJECT AND 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, generation of heat and power for commercial and public buildings, a new hydrogen-refuelling station and injection into the island's gas pipeline network. The project includes the development of a roadmap to 2050 in Mallorca and replication activities on seven other islands.

NON-QUANTITATIVE OBJECTIVES

Green Hysland aims to develop public awareness and create a base for skills development. The project has been presented at almost 60 events. 5 workshops have been conducted and 11 activities have been organised jointly with other EU projects.

PROGRESS AND MAIN ACHIEVEMENTS

- Green Hysland has delivered and installed a 2.5 MW electrolyser.

- The project awarded the tender for the EMT Palma H₂ buses.
- The project completed the conceptual design of the 6 project sites.

FUTURE STEPS AND PLANS

- The H₂ plant will go into operation. The electrolyser was delivered in December 2021 and the plant is expected to be operational from summer 2022.
- The tender for H₂ buses was launched in December 2021 and was awarded in March 2022. They are expected to be delivered in the first quarter of 2022.
- During 2022, tenders are expected to be launched for the purchase of the fuel cells for the Puerto Deportivo Naviera Balear, Lloseta and hotel sites in Palma, and for a fleet of 10 vehicles (rental cars and vans). The project is working on defining the technical and administrative specifications of the tender documents.
- The sites are expected to receive the equipment in June 2023. At least 2 years of operation of the complete ecosystem is expected within the project period.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?
Project's own objective	Electrolyser	MW	7.5	2.5	

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HEAVENN

HYDROGEN ENERGY APPLICATIONS FOR VALLEY ENVIRONMENTS IN NORTHERN NETHERLANDS

New Energy Co



Project ID	875090
PRD 2022 Panel	6 – H2 valleys
Call topic	FCH-03-1-2019: H2 valley
Project total costs	EUR 96 191 883.93
Clean H ₂ max. contribution	EUR 20 000 000
Project period	1/1/2020 – 31/12/2025
Coordinator	Stichting New Energy Coalition, the Netherlands
Beneficiaries	Shell Nederland Verkoopmaatschappij BV, TotalEnergies Marketing Nederland NV, TotalEnergies Gas Mobility BV, Gemeente Hoogeveen, Hydrogen Ireland Natural Resources Association Company LBG, Nederlandse Particuliere Rijnvaart-Centrale Coöperatie UA, UVO Vervoer BV, Lenten Scheepvaart BV, Bytesnet Groningen BV, EWE Gasspeicher GmbH, Energy BV, Green Planet Real Estate BV, Emmtec Services BV, Gemeente Emmen, HyEnergy TransStore BV, H2Tec BV, Gemeente Groningen, Groningen Seaports NV, Engie Energie Nederland NV, Energie Beheer Nederland BV, HyEnergy Consultancy Limited, European Research Institute for Gas and Energy Innovation, PitPoint.Crew BV, PitPoint. Pro BV, Qbuzz BV, Nederlandse Aardolie Maatschappij BV, PitPoint.CNG BV, Cemtec Fonden, Gemeenschappelijke Regeling Samenwerkingsverband Noord-Nederland, Logan Energy Limited, Hincio SA, Stichting Energy Valley, Nobian Industrial Chemicals BV, Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón, NV Nederlandse Gasunie, European Marine Energy Centre Limited, Rijksuniversiteit Groningen

<http://www.heavenn.org/>

PROJECT AND OBJECTIVES

HEAVENN is a large-scale demonstration project bringing together core elements – production, distribution, storage and local end use of H₂ – 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 H₂ across the entire value chain, while developing replicable business models for wide-scale commercial deployment of H₂ across the entire regional energy system.

NON-QUANTITATIVE OBJECTIVES

- HEAVENN aims to achieve regulations, codes and standards certification. All relevant green H₂ value chains will be tested against the CertifHy protocol.
- Safety issues will be covered by permitting procedures.

PROGRESS AND MAIN ACHIEVEMENTS

- The H₂ salt barge's design and build contract was signed. The long-term contract for deployment of a H₂-powered vessel for internal transport of salt on the Delfzijl–Rotterdam route was finalised. The design of the ship and configuration of the H₂-electric propulsion were initiated, including a fluid dynamics calculation to determine the required installed capacity and hull shape.

- Gasunie successfully conducted the first static tests and demonstrated that H₂ can be safely stored in salt caverns. The connections 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 H₂ caverns are in progress.
- The detailed design and site layout plan of and permit application for the Emmen hydrogen-refuelling station were completed. The launching customer has been secured. Commissioning is planned for June 2022.

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.
- Securing co-funding is a prerequisite for the project to succeed. Talks with governments about State aid will continue, aiming to speed up the process and secure all co-funding in 2022.
- Much effort will be put into connecting the various hydrogen valley projects, sharing experiences and lessons learnt, creating synergies and thus strengthening each other.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
MAWP 2014–2020	Fuel cell and hydrogen passenger cars					
	FC system cost	€/kWh	60		100	2019
	H ₂ production (electrolysis) – PEM					
	Energy commission consumption	kWh/kg	50		55	2020
	Storage, distribution and H ₂ supply					
	Large storage system cost	€/kg	0.8		N/A	–

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PILLAR 7 – SUPPLY CHAIN

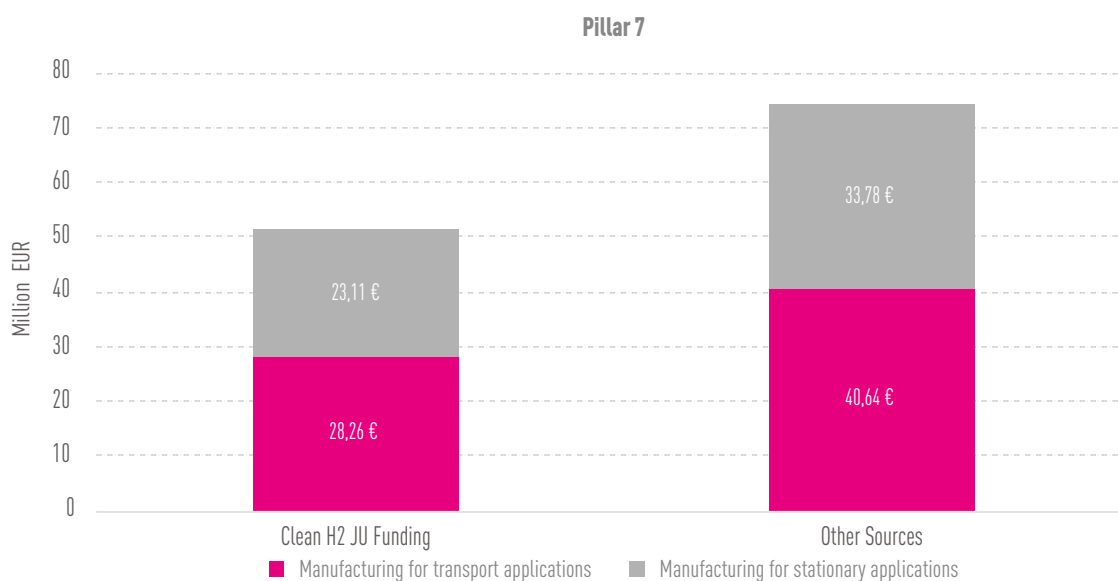
Objectives: The main objectives of this Pillar, according to the SRIA, can be summarised to:

1. Identification of potential vulnerabilities in EUs hydrogen supply chain;
2. Development of new and improved manufacturing technologies and production processes that facilitate the safe and sustainable use of non-critical (raw) materials as well as facilitate the adoption of the circular economy principles;
3. Reducing the use of critical (raw) materials with sustainability or environmental concerns, such as for instance those deriving from poly/perfluoroalkyls.

According to the MAWP, the overall goal of projects in this research area is to make possible efficient manufacturing of large volumes of PEM and SO fuel cell technologies with improvements with respect to current costs, FC performances and environmental impact. Noticeable improvements have been obtained by FC products obtained with innovative manufacturing methods. Even if improvements can be detected for many KPIs linked with performance, it seems that CAPEX is a crucial parameter still far away from the expected values.

Budget: Between 2010 and 2020, the JU supported 17 projects relevant to this pillar with a total contribution of EUR 51.3 million and a contribution from partners of EUR 74.4 million. The historic distribution of total budgets over the 2 research areas is shown in Figure 58 and indicates that 55% of FCH 2 JU funding went to support 7 projects on manufacturing for transport applications and 45% was dedicated to 10 projects on manufacturing for stationary applications. The FCH JU funding contribution amounts to about 41% of the total funding for the portfolio of projects considered in this Pillar.

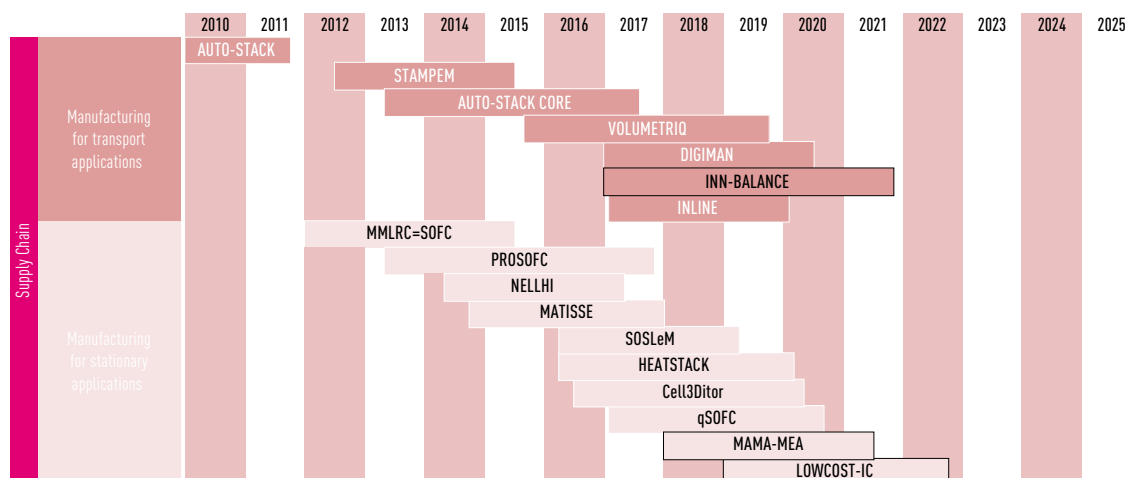
Figure 58: Funding for Pillar 7 projects from 2008 to present.



Source: Clean Hydrogen JU

Projects: The Clean Hydrogen JU projects overview for Pillar 7 related projects is shown in Figure 59.

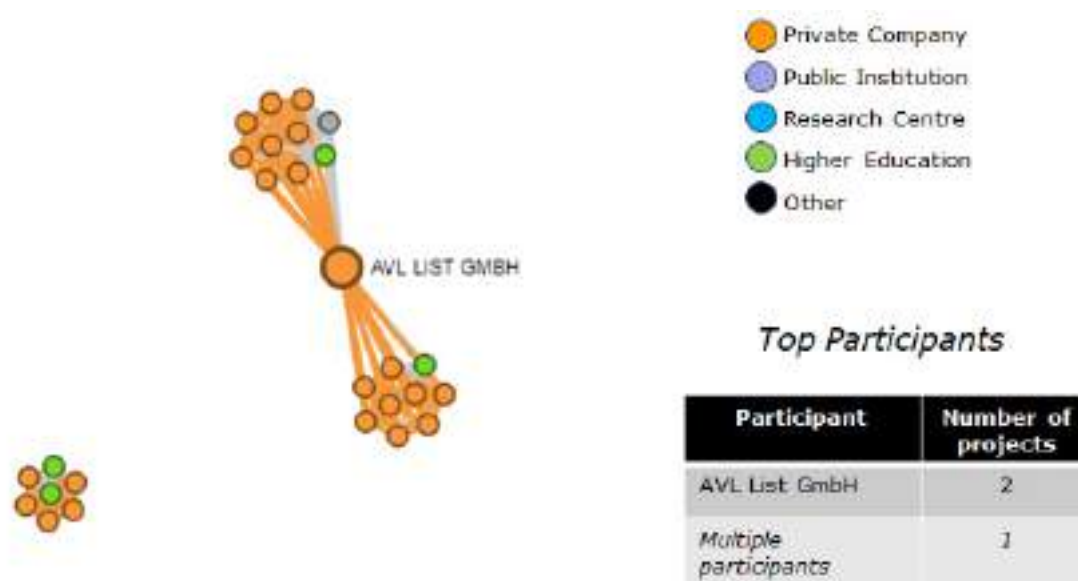
Figure 59: Project timelines of Pillar 7 – Supply chain. Projects highlighted in black were considered for the 2022 Programme Technical Assessment.



Source: Clean Hydrogen JU

The TIM plots showing the main organisations and EU Member State contributing to Pillar 7 are shown in Figure 60.

Figure 60: TIM plot showing the participants of the 3 projects in Pillar 7.¹⁴²



Source: TIM (JRC)

142. 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.

MANUFACTURING FOR STATIONARY APPLICATIONS

MAMA-MEA main objective was to set up an innovative additive layer deposition process using a single, continuous roll-to-roll MEA manufacturing process for the PEMFC. The project finished in June 2021 including 6 months agreed extension. The manufacturing of the catalyst layers and the reinforced membrane has been done using slot die coating.

A concept of production line was designed. Production line was developed up to Manufacturing Readiness Level (MRL) 6. Further work should be focused on producing some prototype modules that need operational proof of concept. The manufacturing technology proved viable for the manufacturing of sealed CCMs for full size fuel cell stacks. JMFC already earmarked the construction of a production facility leveraging the technology developed in MAMA-MEA. The LCA encompassed a projected life cycle of 20 years, estimating the capital and operational expenditure at about EUR 13-18 million, depending on the scenario.

LOWCOST-IC aims at applying a state-of-the-art large-scale roll-to-roll manufacturing approach for increasing the reliability and decreasing the cost of interconnects in SOFC. The selection of suitable new materials for metallic interconnects also has the goal of increasing SOFC stack lifetime. The project has already shown good results with tangible improvements over state of the start in terms of possible material and manufacturing process.

Novel contact layers with high mechanical robustness based on Co, Mn and Cu, Mn spinels have been achieved. Where the former shows better chemical stability, the latter shows exceptionally high mechanical robustness. New combinations will be explored. New interconnect design was obtained with the possibility of including a cell which is 30% thinner (60 μm rather than 90 μm thick electrolyte). Stack tests have been run for 3,000 hours, but thermal cycling of stacks with new contact layers have not been carried out at this point in the project. Stacks with steel type Sanergy® HT 441 were produced with the existing interconnect shaping methods and tested. For high temperature operation (850 $^{\circ}\text{C}$) at Sunfire, it was shown that Sanergy 441 HT corroded faster than the rather expensive Crofer 22 APU steel. The reason will be investigated in the second half of the project.

MANUFACTURING FOR TRANSPORT APPLICATIONS

INN-BALANCE has finished on Jun 30th, 2021 including 6 months agreed extension. The goal was to develop highly efficient and reliable fuel cell BoP components and therefore reduce the cost of current market products in FCS; improve and tailor development tools for design, modelling and testing of innovative components in fuel cell-based vehicles. All expected BoP components were developed and tested at subsystem level, and then they were successfully integrated into a vehicular platform performing verification of their operation under automotive conditions with some derogations due to lack of time caused by the Covid-19.

The analysis, packaging study, FCS assembly and vehicle integration has proven that it is possible to build an FCEV and operate the FCS in question on the vehicular platform. The designed software and control structure is proved to work properly in the real time vehicle tests on road. The state-machine, as the central part of the supervisory controller, coordinates the BoP subsystems and the FCS processes, such as start-up and shut-down. Ultimately a car that runs independently on hydrogen has been developed. The project is now closed but partners reported during the exploitation workshops that actions will be taken after project end to further develop the INN-BALANCE components to reach other key markets and higher TRL levels to achieve fast commercialisation.

INN-BALANCE

INNOVATIVE COST IMPROVEMENTS FOR BALANCE OF PLANT COMPONENTS OF AUTOMOTIVE PEMFC SYSTEMS



Project ID	735969
PRD 2022 Panel	7 – Supply chain
Call topic	FCH-01-4-2016: Development of industrialization-ready PEMFC systems and system components
Project total costs	EUR 6 156 288.75
Clean H ₂ max. contribution	EUR 4 994 538.75
Project period	1/1/2017 – 31/10/2021
Coordinator	Fundación Ayesa, Spain
Beneficiaries	China Euro Vehicle Technology Aktiebolag, Steinbeis 2i GmbH, Brose Fahrzeugteile GmbH & Co. Kommanditgesellschaft, Würzburg, Celeron AG, PowerCell Sweden AB, Steinbeis Innovation gGmbH, Volvo Personvagnar AB, AVL List GmbH, Universitat Politècnica de Catalunya, Deutsches Zentrum für Luft- und Raumfahrt EV

<https://www.innbalance-fch-project.eu>

PROJECT AND OBJECTIVES

The aim of INN-BALANCE was to develop a novel and integrated development platform for developing advanced balance-of-plant components in current fuel-cell-based vehicles in order to improve their efficiency and reliability, reducing costs and presenting a stable supply chain to European car manufacturers and system integrators.



PROGRESS AND MAIN ACHIEVEMENTS

- INN-BALANCE has created an optimised ejector for the automotive fuel cell stack.
- The project has created a high-speed air compressor for the automotive fuel cell.
- It has created an antifreeze module for the automotive fuel cell.

FUTURE STEPS AND PLANS

The project has finished.

QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Target achieved?
Project's own objectives	Power: air turbo compressor	kW	10–12	
	Thermal management system	°C	– 40	
	Fuel cell system's efficiency and lifetime	%	5 (efficiency), 10 (lifetime)	

LOWCOST-IC

LOW COST INTERCONNECTS WITH HIGHLY IMPROVED CONTACT STRENGTH FOR SOC APPLICATIONS

Project ID	826323
PRD 2022 Panel	7 – Supply chain
Call topic	FCH-02-6-2018: Cost-effective novel architectures of interconnects
Project total costs	EUR 2 335 997.50
Clean H ₂ max. contribution	EUR 2 335 997.50
Project period	1/1/2019 – 30/9/2022
Coordinator	Danmarks Tekniske Universitet, Denmark
Beneficiaries	Tecno Italia SRL, Sunfire GmbH, SOLIDpower SpA, Borit NV, Aperam Stainless France SA, Aktiebolaget Sandvik Materials Technology, AVL List GmbH, Chalmers tekniska högskola AB, Forschungszentrum Jülich GmbH

<https://www.lowcost-ic.eu>

PROJECT AND OBJECTIVES

The overall objective of LOWCOST-IC is to contribute to the successful upscaling of the widespread commercialisation of solid oxide cell (SOC) technologies by:

- increasing the robustness of the lifetime of SOC stacks by developing novel high-robustness air electrode contact layers and testing new interconnect coatings in SOC stacks;
- minimising the interconnect development and production cost by introducing cheaper high-volume steel, applying state-of-the-art (SoA) large-scale roll-to-roll manufacturing

methods for SOC manufacturing, and developing a novel interconnect shape design route.

PROGRESS AND MAIN ACHIEVEMENTS

Robust contact layers were developed.

FUTURE STEPS AND PLANS

LOWCOST-IC will perform postmortem analysis of the contact layers tested in the stacks. Samples have been cut out from commercial stacks being tested with the new contact material. Postmortem analysis under a microscope will be undertaken shortly.



QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Achieved to date by the project	Target achieved?	SoA result achieved to date (by others)	Year of SoA target
Project's own objectives	Fracture energy of contact layer	J/m ²	5.1	10	✓	1.7	2013
	Area-specific resistance of contact layer at 750 °C	mohm.cm ²	15	60	⚙️	15	2019
	Area-specific resistance of contact layer at 850 °C	mohm.cm ²	25	21	✓	N/A	N/A

MAMA-MEA

MASS MANUFACTURE OF MEAS USING HIGH SPEED DEPOSITION PROCESSES

Project ID	779591
PRD 2022 Panel	7 – Supply chain
Call topic	FCH-02-8-2017: Step-change in manufacturing of fuel cell stack components
Project total costs	EUR 3 189 816
Clean H ₂ max. contribution	EUR 3 189 816
Project period	1/1/2018 – 30/6/2021
Coordinator	Technische Universität Chemnitz, Germany
Beneficiaries	System SpA, Johnson Matthey Fuel Cells Limited, Inea Informatizacija Energetika Avtomatizacija DOO, Nedstack Fuel Cell Technology BV, Università degli Studi di Modena e Reggio Emilia, Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung EV

<https://www.mama-mea.eu>

PROJECT AND OBJECTIVES

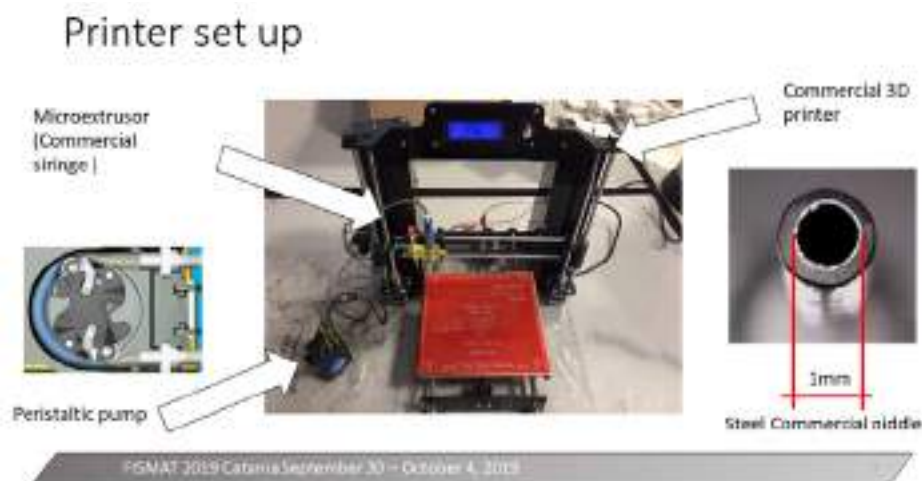
The task of MAMA-MEA was to develop an innovative additive layer deposition process integrating all main catalyst-coated membrane components (membrane, catalyst layers, sealing) using a single, continuous roll-to-roll manufacturing process for the proton-exchange membrane fuel cell industry. This will enable a more than 10-fold increase in the volume manufacturing rate compared with state-of-the-art processes, while also increasing key material utilisation, and reducing the quantity of materials and their costs. The project was successfully completed by 30 June 2021.

PROGRESS AND MAIN ACHIEVEMENTS

- MAMA-MEA completed the engineering design.
- The project evaluated deposition techniques.
- It performed experimental validation.

FUTURE STEPS AND PLANS

The project is finished. The target manufacturing speed was reached; however, additional process optimisation is required to increase the lifetime.



QUANTITATIVE TARGETS AND STATUS

Target source	Parameter	Unit	Target	Target achieved?
AWP 2017	CAPEX	€/kW	55	⚙️
	Lifetime	hours	20 000	
	Degradation rate	%/1 000 h	< 1	
Project's own objectives	Production/web speed	lm/s	0.84	✓

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